FINAL REPORT

Modular Biopower System Providing Combined Heat and Power for DoD Installations

ESTCP Project EW-200940

DECEMBER 2013

Kingsbury Browne
James Diebold
Community Power Corporation

Distribution Statement A

This document has been cleared for public release

SECURITY REVIEW – SF298

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
12/09/2013	Final	9/19/2009 - 12/31/2013

4. TITLE AND SUBTITLE	
Modular Biopower System Providing Combined Heat and Power for DoD Installations	**5a. CONTRACT NUMBER** W912HQ-09-C-0059
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER** ESTCP: SI-0940
James P. Diebold Kingsbury Browne	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Community Power Corporation 14800 Grasslands Dr. Englewood, CO 80112	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Community Power Corporation developed a 100-kW electrical, automated system (BioMax®) to gasify biomass into a clean gas for fueling a spark-ignited engine/genset. The BioMax® was tested at Ft. Carson, CO, meeting or exceeding nearly all of the program goals. Maximum sustainable, net electrical power was 83 kW (goal-75 kW). Maximum sustainable thermal energy output was 180 kW (goal-150 kW). Highest monthly availability was 73%. The BioMax® 100 has a relatively high capital cost, making it difficult to compete with grid power in most Dept. of Defense locations. However, operating the BioMax® is advantageous when compared to high fuel cost energy generation (e.g. remote locations or TQG operation).

15. SUBJECT TERMS

biopower; combined heat and power (CHP); distributed generation; gasification; gensets

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Kevin Buelke
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	61	(303) 933-3135

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

APEN	Air Pollutant Emission Notice
Btu	British Thermal Unit = 1055 Joules
Btu/SCF	British Thermal Units per Standard Cubic Foot (at 60°F and 30 in. Hg)
CDPHE	Colorado Department of Public Health and Environment
CHP	Combined recovered heat and electrical power
CPC	Community Power Corporation (a wholly owned subsidiary of Afognak Native Corporation)
DPW	Directorate of Public Works
ESTCP	Environmental Security Technology Certification Program
g/hphr	grams per horsepower hour
FPM	Feed Preparation Module
GEN2	Second generation version of the BioMax® 100 system
GPM	Gas Production Module
HC	hydrocarbon compounds
hp	shaft horsepower
hp-hr	horsepower hour
k	kilo = 1000
kW	kilo Watts
kW_e	kilo Watts of electrical energy
kW_{th}	kilo Watts of thermal energy
HDR	HDR Environmental, Operations, and Construction, Inc.
lb/hr	pounds per hour
M	Mega = 1,000,000 (used with metric units)
MMBtu	million Btu
PGM	Power Generation Module
PM	Particulate Matter in air emissions
PPM	Power Production Module
ppm	parts per million
ppmdv	parts per million dry volume basis
RCRA	Resource Conservation and Recovery Act
SERDP	Strategic Environmental Research and Development Program
SNL	Sandia National Laboratory
TCLP	EPA's Toxicity Characteristic Leaching Procedure
THC	Total Hydrocarbon
TQG	Tactical Quiet Generator
USAFA	United States Air Force Academy
VOC	Volatile Organic Compounds (except formaldehyde)

ACKNOWLEDGMENTS

The authors, King Browne and James Diebold, wish to acknowledge the contributions made to this program by Fort Carson, the Fort Carson Directorate of Public Works, its Utility Programs Manager, Vince Guthrie, and the exceptional team at Ft. Carson who assisted in making this site demonstration successful.

We want to thank ESTP for providing the funding for this project and the guidance provided by Dr. Jim Galvin, EW Program Manager and his team.

We also wish to acknowledge Community Power Corporation (CPC) personnel who played an integral role in the project success: John Steele, Carl Peterson, Andrew Freeman, Art Lilley, Mark Stewart, Chad Cooper and Kevin Splant.

EXECUTIVE SUMMARY

The Department of Defense (DoD) has been mandated to increasingly derive energy from renewable resources. Community Power Corporation (CPC) has researched and developed the 100-kW electrical, automated turn-key BioMax® system to gasify biomass to make a clean gas suitable for fueling a spark-ignition engine to power an electrical generator. Initial testing of a smaller 50-kW BioMax® system with walnut shells demonstrated that only one part-time operator was necessary to operate the system 24 hours per day, 7 days per week with a high level of availability. This program tested the first prototype 100-kW BioMax® system at CPC and under field conditions.

A review of DoD installations revealed that 170 of them had access to significant amounts of woody biomass materials within a 25-mile radius and an interest in alternative energy. It was also recognized that this first prototype system would need continuing technical support from CPC, so a field-test site close to CPC was desirable. It was rationalized that the data generated at one DoD site could extrapolated to a large number of other DoD sites, taking into account differences in feedstock costs, local energy costs, local labor costs, etc. For these considerations, the selected test site was at Fort Carson, Colorado, which was relatively near to CPC's headquarters and which had personnel dedicated to increasing the use of alternative energies. Woodchips salvaged commercially from Beetle-killed pine were selected as the feedstock.

The first prototype BioMax® 100 was tested extensively at CPC with Beetle-killed-pine chips. Prior to shipping to Fort Carson, exhaust emission testing showed that the system had extremely low levels of emitted pollutants in the exhaust gas. The projected maximum yearly air emissions were so small, that it appeared that a permit to operate the BioMax® 100 was not required by the State of Colorado. None the less, Fort Carson required a Colorado permit to operate the system on its premises, which resulted in a significant program delay.

After a short period of operation, the custom-designed engine developed mechanical problems, which resulted in its replacement with two General Motors spark-ignited engines that CPC had modified slightly to accommodate fueling with gasoline, producer gas, or a combination of the two during startup of the gasifier. Fueling with gasoline only occurs during startup of the system. This required new gaseous emission testing and a new operating permit, which delayed the field testing several months.

The commissioning period at Fort Carson lasted much longer than planned before unattended operation was attained. This prototype system required numerous control code changes and some minor equipment changes. Nearly all of the program goals were met or exceeded. For example, the maximum sustainable, net electrical power at Fort Carson's elevation was 83 kW (104 kW net at sea level), compared to the goal of 75 kW at an unspecified altitude. The maximum sustainable recovery of waste engine heat was 180 kW thermal, which extrapolates to 226 kW thermal at sea level, compared to the goal of 150 kW thermal recovered.

During this field test, the BioMax® 100 had a steadily increasing availability for the system that was approaching the program goal of 80%. The highest monthly availability attained was 73%, occurring in the last month of the field test.

A life-cycle cost analysis was performed for the BioMax® 100 system operating as a base-load provider, which showed that the small system had a relatively high capital cost, but a relatively low fuel cost assumed to be $40/dry ton (about $3.50/MMBtu, if the wood were burned in a boiler operating at 80% efficiency). Feedstock cost varies from a negative, avoided disposal cost to in excess of $100/dry ton based upon the site, transportation logistics, etc. The assumed $40/dry ton is reasonable average based upon CPC's experience with BioMax® Systems at various locations in the contiguous United States. A BioMax® System cannot compete economically with grid power in most DoD locations, except in Hawaii and other remotely located facilities having very high fossil fuel costs.

For the case of generating electricity at sea level (assuming no recovery of waste heat) with the BioMax® 100 system, the electricity produced must be valued at over $0.335/kW$_e$h to result in a simple payback period of seven years or less. With recovered waste heat, seven-year simple payback periods can be achieved with lower electrical values, which depend upon the value of the displaced fuel used for heating. For example, with a heating fuel cost of about $4.65/MMBtu (Contiguous U.S. industrial average 2013 for natural gas), the electrical value needs to be over $0.29/kW$_e$h. For with the displaced heating fuel cost of $4.10/gal of fuel oil, the electrical value can be near zero with waste heat recovery for a simple payback period of seven years. Operating the BioMax® 100 system at higher elevations results in engine derating and consequently lower levels of electrical generation and recovered waste heat levels, both of which impact negatively on the economic projections,

The BioMax® 100 has difficulty competing with electrical grid power and natural gas in the contiguous United States. However, for remote locations that are not served by the grid or by natural gas, the BioMax® 100 is very competitive with long term generation of electrical power and recovered waste heat compared to generating the same amount of power with two 60 kW Tactical Quiet Generators (TQG's). Operating the BioMax® 100 over an assumed 15-year life with biomass at $40/ dry-ton is projected to have a Life Cycle present value of +$323,904, compared to producing the same amount of electrical power using two 60-kW TQG's, fueled with diesel at an assumed average contiguous U.S. price of $4.10/gallon having a present value of -$3,308,559. Over the long run, the lower cost of biomass, compared to JP-8, more than compensates for the initial high capital cost of the BioMax® system.

1.0 INTRODUCTION

The Department of Defense (DoD) has increasingly recognized that its energy use at installations and in operations is occurring at levels that must be comprehensively reduced and must be increasingly derived from a greater percentage of renewable energy sources. The DoD must strive to meet the requirements of Congressional legislation and Executive Orders which mandate change in our nation's energy consumption and production. The Energy Policy Act of 2005 (EPACT 2005) requires Federal agencies to purchase 7.5% of their energy from renewable sources by 2013; Executive Order 13423 requires that half of this renewable energy come from new sources; and the National Defense Authorization Act of 2007 (NDAA 2007) requires that 25% of DoD's total electricity come from renewable sources by 2025.

The legislated energy mandates and cultural initiatives support DoD-wide goals of improving its resiliency and endurance as a military force. These include: 1) Surety: Preventing loss of access to power and fuel sources. 2) Supply: Accessing alternative and renewable energy sources available at the installation. 3) Sustainability: Promoting support for DoD's mission, its community, and the environment. 4) Sufficiency: Providing adequate power for critical missions. 5) Survivability: Ensuring resilience in energy systems.

Many DoD facilities have large land areas containing significant biomass resources. Typically biomass is left onsite to decompose or is land-filled at great expense, but not used as fuel. Converting this biomass resource to heat and/or electricity lowers an installation's dependency on imported fossil fuels and directly contributes to the DoD's above stated energy goals.

The thermal conversion of biomass to energy requires that its organic content be oxidized completely into carbon dioxide and water. This thermal conversion is a multi-step process. In the presence of heat, biomass first decomposes to form combustible gases, tar vapors, and char in a process called pyrolysis. If a small amount of air is added to the pyrolyzing biomass to combust some of these gases to provide this heat, the process is termed gasification and the gases are termed "producer gas." This type of gas was used historically in residences and industry before natural gas became widely available.

If this producer gas is cooled before further combustion, it can be processed into a clean gas suitable for use as fuel in an internal combustion engine or other combustion device such as a boiler. Additional air is needed to completely burn the gases.

Biomass gasification is the first step in biomass combustion. In modern biomass stoves, boilers, and furnaces, "primary" air achieves partial combustion of the biomass (gasification) and "secondary" air achieves complete combustion of the gases.
Historically, conversion of biomass to heat or electricity required the use of combustion technology, where the biomass was completely burned in a single process in a boiler. This technology requires a relatively large scale facility to be permanently installed at a location and requires assurance of a long term fuel supply. Certain DoD facilities are sustainable generators of biomass, but typically not at the large volume needed for combustion technology. A new

technology has been needed to efficiently convert the solar energy stored in relatively small (a couple of semi-truck/trailers per week) volumes of waste biomass into useful energy forms.

The goals of CPC in this project were to demonstrate the use of gasification technology to efficiently and reliably convert waste woody biomass material into useful energy at Fort Carson, Colorado. CPC's goals included the operation of the prototype BioMax® 100 system at over 75 kW_e and for 80% or more of the time the unit was being demonstrated in the field. The demonstration provided operational data for DoD to evaluate the technology for suitability at other installations. Data included: 1) Labor requirements; 2) Emissions; 3) Site considerations; 4) Permitting processes; 5) Preventive maintenance requirements; 6) Corrective maintenance needed during the demonstration period; 7) Energy generation trends, including peak, minimum and variances noted; and 8) unusual operating characteristics at start up or shut down.

This contract was modified in May of 2012 to add additional work to upgrade the electricity generating engines/build a new power generation module and to extend the period of performance to allow demonstration continuation with the enhanced hardware. The new performance period was extended to August 2013 due to delays caused by Federal and state governments and to cover this additional work. The originally contracted period of performance was two years, but this last contract extension increased the period of performance to a total of nearly four years;
The demonstration continuation commenced in February, 2013, and lasted for six months, pursuing the goal of operating at 80% or higher capacity factor at the rated output (equivalent to about 100 kW_e at sea level).

1.1 BACKGROUND

Gasification of biomass was widely practiced in the past. Producer gas was generated for municipal use before the local availability of natural gas and in World War II in Europe and Japan due to fossil fuel shortages. The old gasification technology that was used to make the producer gas was labor intensive, because process automation had not yet been developed. The producer gas contained large amounts of carbon monoxide, hydrogen, carbon dioxide, and nitrogen. The old technology also co-produced large amounts of tars and tarry water that had to be removed prior to using the gas as fuel in efficient engines. The tars were compounds that were relatively thermally stable at the gasification temperatures and were composed of polycyclic aromatic compounds (PAH), some of which were partially soluble in water. The environmental disposal of these tars and tarry water is an unacceptable burden today and has precluded the use of biomass gasification, especially in small scale systems.

Recent advances in gasification technology by CPC have resulted in the ability to gasify biomass to produce a clean fuel gas containing low amounts of water vapor and negligible residual particulates and tars. The gas is used to fuel internal-combustion engines to produce heat and power. CPC has coupled this new gasification technology with modern automated-process controls in their BioMax® systems that provide the ability for one operator to safely operate multiple systems unattended and remotely 24/7 via the internet.

Due to the distributed nature of the biomass resource, CPC believes that the optimal size of the biomass gasifier system should be relatively small, compared to typical power plants making

megawatts of electrical power, to enable the use of locally available biomass and to keep the biomass transportation costs low. CPC modular gasifier systems are factory built and can be transported and commissioned near to where the biomass is located. These sustainable, modular systems use locally grown waste biomass to produce electrical power and heat, which can be utilized very efficiently onsite without traditional utility transmission losses.

The energy content of biomass is proportional to the weight of the bone-dry (0% moisture) material. Any moisture in the wood will be evaporated during the gasification process and result in a lower energy efficiency. It is therefore misleading to state the weight of biomass consumed in an alternative energy process, without also specifying the moisture content of the biomass. There are two different bases used to express the moisture content of wood, the "wet" basis and the "dry" basis. The dry basis is defined as the weight of water per weight of dry biomass. This report uses the wet basis, which is the weight of water per weight of wet biomass. At 0% moisture, these two bases are identical in numerical value. Using these definitions, one can easily convert from the wet basis to the dry basis and *vice versa*. The amount of dry biomass required will be primarily proportional to the energy output required and vary to a lesser extent with the energy efficiency of the system used and the moisture content of the feedstock. Therefore, a system's feedstock consumption rate should be stated on a 0% moisture basis, to allow conversion to the site specific biomass-moisture contents and biomass weight requirements.

The combustion of biomass is considered to be environmentally neutral with respect to greenhouse gas emissions, because it is viewed as recycling contemporary carbon. However, if burning biomass results in the displacement of fossil fuels, then it would be preventing the emission of fossil-derived CO_2 into the atmosphere and be "carbon negative". For example, one 100-kW_e net modular biopower system operating at 80% availability can convert 778 tons of biomass (0% moisture or bone-dry basis) per year into 701,000 kW_eh and conservatively 1000 MMBtu of recovered thermal energy. If the electricity from the modular biopower system were used to displace grid power, each 100-kW system would reduce CO_2 emissions by 642 tons per year[1]. If the recovered waste heat is used to displace the use of natural gas, then an additional 60 tons of CO_2 would be avoided. Conversely, if the biomass were landfilled, much of it would decompose to form methane, which has a greenhouse effect 21 times stronger than CO_2 in the atmosphere.[2] Landfilling is recognized as the largest source of anthropogenic methane emissions in the U.S.[3]

The use of char made from biomass as a soil amendment has recently received considerable interest as "terra preta" (black earth). This biomass derived char, or "biochar", contains nearly all of the mineral content of the biomass, but concentrated in the char, including potassium, calcium, phosphorous, trace elements, etc. Depending upon the biomass used and the thermal processing used, biochar can have the physical properties of activated carbon and have a slow release of its mineral and nitrogen content over time. Biochar is a very stable material, can remain in the soil for extended periods of time and result in the sequestration of carbon for hundreds of years.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of the demonstration was to generate data under realistic conditions on a DoD facility to allow preliminary, meaningful analyses of the technical and economic viability of the BioMax® technology for widespread deployment at specific DoD facilities in the future. These necessary data include the system's carbon footprint, payback period, drier performance, producer gas quality (heating value and the levels of tars and particulates of the producer gas), operational availability, reliability (initial mean time between failures and mean time to repair), ease of use (labor to operate), recurring costs, net power and heat production, emissions quality (CO, NOx, and THC), and byproduct char quality, usage or disposal (heavy metal content and TCLP).

1.3 DRIVERS

In addition to the legislation and Executive Orders described in section 1.0, there are additional drivers addressed by CPC's technology. These include contributions to energy security, lower energy costs, lower landfill costs, and environmental imperatives. By making DoD facilities more energy independent and self-sufficient, security from interruptions in the energy supply lines is enhanced. To the extent that local energy resources can be utilized, military bases can operate with decreased regard to political and economic forces that potentially threaten an increasingly foreign-sourced energy supply.

Energy costs can be more easily controlled and less subject to political or security induced price swings if the sources of energy for DoD facilities are local and renewable. This frees up finite financial resources for hardware and logistical expenditures.

Landfilling costs can be reduced or eliminated, if waste streams generated on site can be converted to an energy resource.

The carbon in biomass is considered to be contemporary carbon, as compared with the carbon in fossil fuels that was sequestered eons ago. Contemporary atmospheric carbon is continuously recycled as plants grow and decay. Whether the biomass is harvested and utilized for energy or naturally decays with no energy recovery, its carbon is released to the atmosphere as carbon dioxide. However, this short term biological absorption and release of carbon does not add to the long term balance of CO_2 in the atmosphere. Consequently, using renewable biomass for energy results in a zero carbon footprint for the energy produced. Overall, the gasification of biomass to produce electricity has a slightly negative carbon footprint, if the relatively small amount of byproduct char is landfilled and protected from slow oxidation by exposure to air.

Finally environmental considerations are taking on increased importance as DoD facilities are seeking to comply with local environmental regulations and permitting requirements and strive to become good neighbors within their communities.

2.0 TECHNOLOGY DESCRIPTION

CPC's BioMax® automated gasification technology converts waste biomass to heat and electrical power, transforming a waste disposal liability into an energy asset.

2.1 TECHNOLOGY OVERVIEW

CPC's automated BioMax® advanced-state-of-the-art technology is based on down-draft gasification with recently developed and patented secondary-air injection to convert tars and char into a usable producer gas with unusually low residual tar content in the gasifier. This ultra low-tar producer gas and entrained fine char and ash are cooled in a uniquely stress-relieved, high-temperature tube-and-shell heat exchanger, and then filtered to remove fine char and ash particulates. The heat from cooling the hot producer gas is recovered as hot air that is used as needed to dry the wet raw feedstock down to a suitable level for gasification in the range of about 8% to 18% (wet basis). The innovatively high level of automation of the BioMax® system results in safe operation with or without an operator in close attendance, allowing around-the-clock operation with only one operator in attendance for part of one shift per day. This automation alerts the operator of problems by texting, with the operator able to remotely change settings via the internet or by advanced mobile phones.

The clean producer gas contains about 18% CO, 16% H_2, 3% methane, 10% CO_2, 9% water vapor, and 44% nitrogen. Figure 1 shows that this producer gas can be burned very cleanly, with a light blue flame. It also burns readily in conventional spark-ignited internal combustion engines used to produce heat and power with low emissions. Producer gas is resistant to pre-ignition and can be used in engines having a relatively high compression ratio without knocking, i.e., it effectively has a high octane rating. For this project, we investigated the use of custom engines with an especially high compression ratio to take advantage of the high effective octanevalue of the producer gas. However, the reliability of these custom engines proved to be poor, forcing us to use conventional, commercial spark-ignited engines instead.

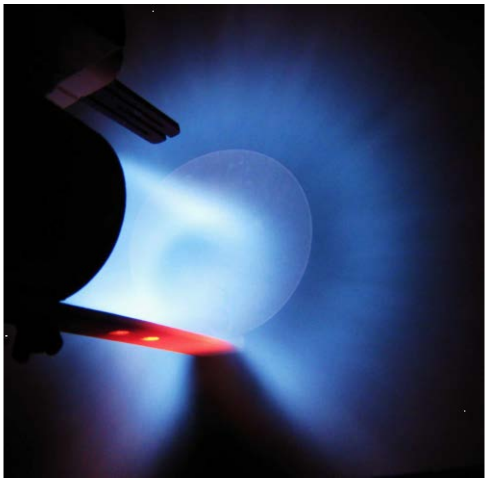


Figure 1. Clean Burning, Blue Flame of Combusted BioMax® Producer Gas

Figure 2 shows a simplified schematic of the CPC downdraft gasifier. Wet woody biomass can have as much as 50% moisture and should be dried to between 8 and 18% prior to gasification in the BioMax® system. The drier in the BioMax® 100 uses cross-flow of hot air through the feedstock after size separation with a vibratory screen. Both the dried feedstock and the primary combustion air enter the top of the gasifier. Feedstock is added until a thick layer of fresh feedstock accumulates near the top of the gasifier, acting as insulation to minimize heat losses. The lower portion of the fresh feedstock is heated by the partial combustion occurring below it, causing it to become completely dry (0% moisture) at temperatures well over 125°C. The water vapor passes downward with the primary combustion air through the gasifier, where it helps to moderate temperatures in the char bed with endothermic reactions that increase hydrogen yields by reacting with CO and char. Immediately below the drying zone, the feedstock is heated to decomposition temperatures and produces char with flammable gas and tar vapors, which ignite in the flaming pyrolysis zone.

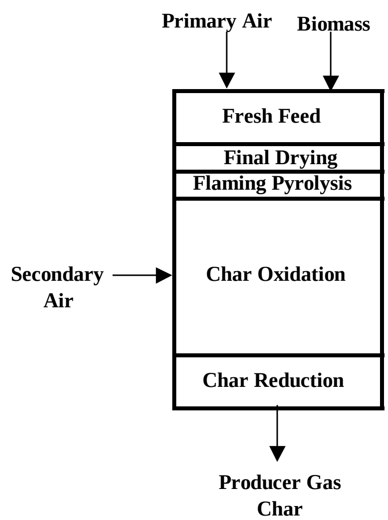


Figure 2. Simplified BioMax® Gasifier Schematic

After the feedstock is converted to charcoal, it slowly moves downward by gravity to enter the char oxidation zone, where secondary air reacts with the charcoal to maintain high temperatures to form a black ash called char. The secondary air also oxidizes the residual tar vapors in the producer gas to convert them to clean fuel gases. Other reactions taking place in the char oxidation zone involve heat absorbing reactions that serve to moderate the temperatures, e.g. CO_2 reacting with char to form CO and water vapor reacting with char to form H_2 and CO. In the char reduction zone with no additional air added, the temperature of the remaining char decreases due to the continued cooling reactions with CO_2 and water vapor. As the char is slowly oxidized over the course of several hours, it moves slowly downward as the char particles become smaller due to oxidation, attrition from periodic gasifier vibration, and by the reciprocating grate action.

Figure 3 shows that the producer gas and the entrained char pass through the reciprocating grate and leave through the bottom of the gasifier. The coarser char drops out between the gasifier and the heat exchanger.

After about a second of residence in the gasifier, the producer gas and the fine char enter the shell-and-tube heat exchanger. The cooled producer gas and the entrained fine char then pass to the filter to remove the particulates at controlled temperatures well above the dew point to keep the water vapor from condensing. The char is cooled as it is augered out of the system, and stored in large plastic drum liners for disposal or preferably sold as a fertilizer, or for use as a carbon adsorbent replacing activated carbon, depending upon the feedstock used and on the local market for char. BioMax® char is quite basic in nature and would be very useful to reduce the acidity of soils, particularly in the eastern U.S. Studies at the University of California, Davis have shown that BioMax® char is an excellent adsorbent for heavy metals.[4]

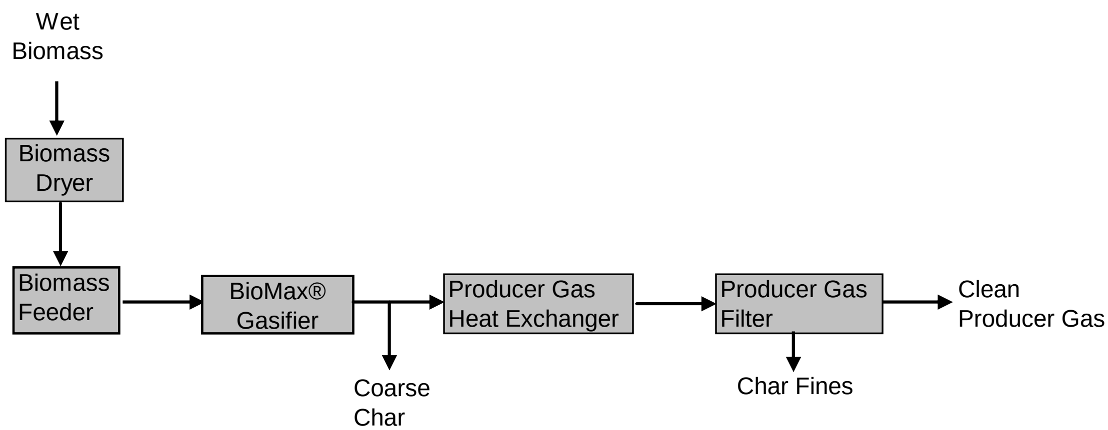


Figure 3. Block Flow Schematic of BioMax® Gasifier

The cleaned producer gas then is mixed with a controlled amount of combustion air and fed to the turbocharger of a spark-ignited internal combustion engine, where the mixture is compressed and used to fuel the engines. The engines turn generators to produce electrical power. The emissions in the exhaust gases are greatly reduced as they pass through 3-way catalytic converters, in the same manner as with an automobile engine.

During system startup before feeding fresh biomass and with only char combustion, the producer gas is relatively weak with a low hydrogen, methane, and CO content resulting in a low energy content, so it was initially diverted to a burner or flare to dispose of it. The need for this flare was eliminated by the development of a dual-fuel capability for the engine, which permitted the engine operation during system warm up and gasifier ignition. All of the gases exiting the gasifier and gas clean up systems pass through the engine in the final configuration of the BioMax® 100, with the flare no longer present.

Waste heat is removed from the engine block and is transferred to the clients heat-transfer fluid. In addition, waste heat is recovered from the exhaust gases with an exhaust-gas heat exchanger using the clients fluid. The two separate heated streams of the client's heat transfer fluid are combined and delivered to the client for use in water heating or space heating applications. If there is no demand for thermal energy, the client's heated heat-transfer fluid passes through an oversized radiator to cool it. This radiator is oversized because it must dissipate both the recovered waste heat from the engine block and from the exhaust gases.

BioMax® systems are totally automated and permit safe, unattended operation after a short commissioning period. The operator is able to check on the system parameters and make control setting changes remotely via the internet. The system is automatically supplied fresh feedstock from the delivery trailer or a large storage bin. During unattended automatic operation, the system continually checks for a large number of parameters that must stay within specified limits, adjusting the control settings in the manner of a constantly alert expert operator. The automated BioMax® system will safely shut itself down in the event of the engine stopping and try to contact the operator by phone if an uncontrollable parameter exists before shutting down the system.

Chronological Development[5] CPC was founded to provide electrification to third-world villages, where 12.5 kW_e can provide a tremendous increase in the standard of living for 80 families. The first field demonstration was in a small village of Alaminos on the island of Panay in the Philippine Islands. This originally included photovoltaic solar panels with battery storage, to which an unsophisticated gasifier and engine/genset was added in 2001, using producer gas made from coconut shells. This gasifier design proved to be troublesome with large amounts of residual tars still in the producer gas that led to excessive maintenance and low system availability. Gasifier system improvements over the next 9 years were made as process automation and the science of gasification were better understood to result in a family of steadily improved automated gasifier designs rated between 5 and 100 kW_e.

The BioMax® 100 gasifier design features:

a) completely automated unattended operation;
b) improved secondary-air injection for the destruction of tars in the producer gas;
c) a grate that can be automatically cleaned of tramp rocks and metal;
d) a self-cleaning shell-and-tube heat exchanger with individually stress relieved tubes for long life;
e) self-cleaning producer-gas filters;
f) automated char removal;
g) feedstock dryers using waste heat recovered from the hot producer gas; and
h) system pre-heaters to avoid moisture condensation during cold startups, etc.
.

Using walnut shells in a BioMax®50 system with most of these features, a total of only one part-time employee was required to keep the automated system operating continuously around the clock for over 31 days.

Figures 4 and 5 show the conceptual layout of the BioMax® 100 system.

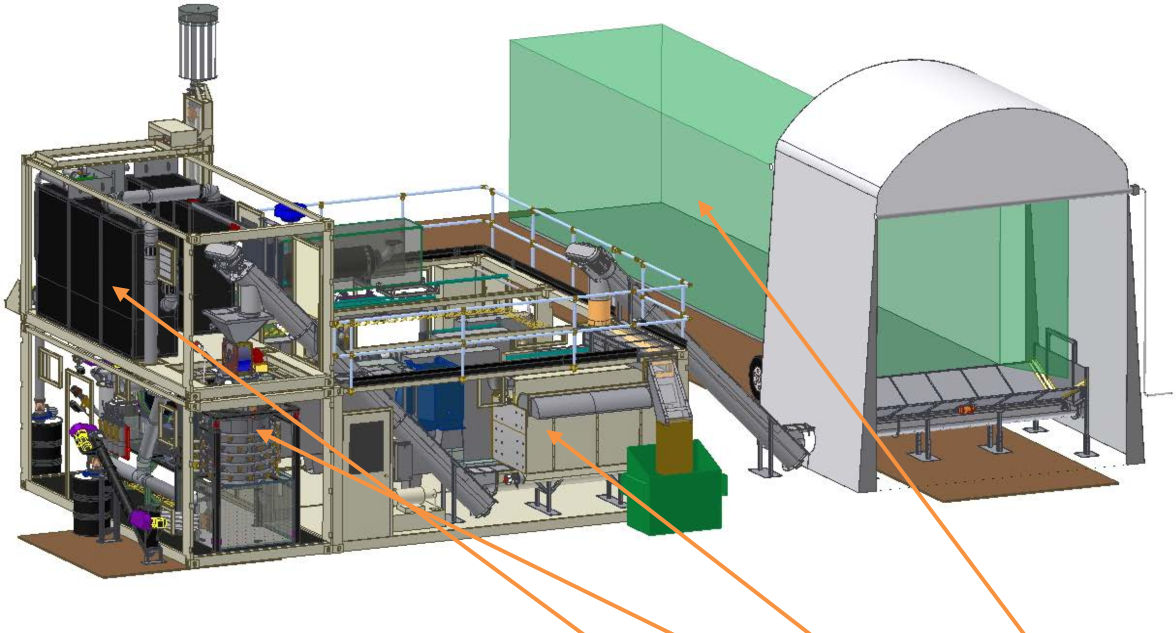


Figure 4. BioMax® 100 – Filter, Gasifier, Feed Processing Modules and Feedstock Trailer

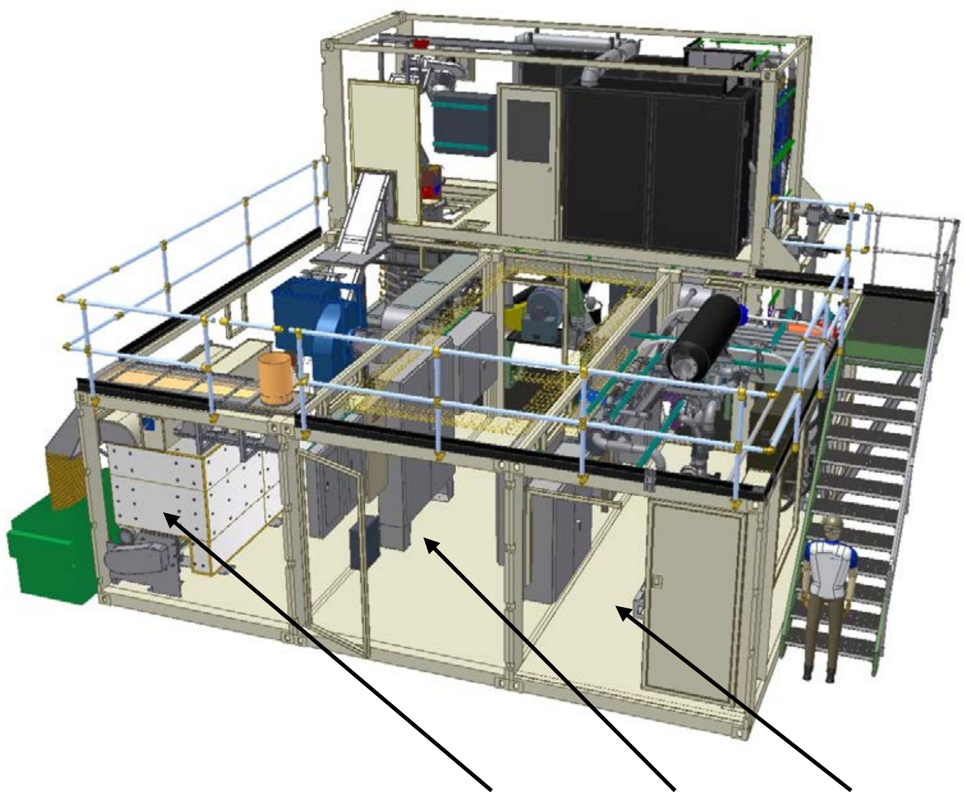


Figure 5. BioMax® 100 Showing the Feed Processing, Control, and Power Modules

2.2 TECHNOLOGY DEVELOPMENT

The BioMax® System technological improvements utilized on this project included the scale up of the system from a size that produced 50 kW of power to one capable of producing 100 kW at sea level. This included a larger diameter gasifier, larger heat exchanger to cool the producer gases, etc. In this project, CPC tried to use a larger, single custom engine/genset, but had to develop instead the ability to use two smaller engine/gensets in parallel.

During system startup and process upsets, producer gas had been sent to a flare for disposal. The measured emissions from the flare were relatively high, leading to a very limited number of permitted hours of annual flare operation. The limited number of hours of flare operation permitted on an annual basis was not sufficient for the commissioning of this first prototype system. So, the engines were modified to be dual-fuel engines capable of burning gasoline, producer gas, or a combination of the two. This resulted in engines that could combust even the normally non-combustible producer gas made during the startup of the gasifier. After startup, the flow of fossil fuel to the engines is gradually reduced to zero and the engines are then fueled only with producer gas during the extended period of operation. This permitted the removal of the flare from the system and a reduction of emissions during startup and during maintenance cycles.

Operating two engines in parallel required upgrading control code and hardware, as we had not previously incorporated this feature in our systems.

A live-bottom trailers to temporarily store and deliver the wood chips to the dryer was first used on this project. Feeding wood chips with augers resulted in frequent jamming of the auger, so the use of belt feeders was implemented.

The BioMax® system used for this demonstration was the first to use the new:

a) Larger BioMax® 100 gasifier design;
b) Woodchip retrieval, sorting, and drying system;
c) Higher capacity producer-gas cooling heat exchanger;
d) Automated char removal systems for coarse gasifier “bottom” char separately from fine “fly” char;
e) Larger 12-L Eliminator V-8 engine; and
f) Modular ISO-container packaging for rapid field deployment, erection, and tear down with “plug and play” features to connect the modules.

These new features presented challenges to resolve for reliable operation.We started with existing control code and significantly expanded and updated its capabilities, based on the many physical changes between the previous systems and this system. These physical changes included a new feed conditioning system (storage, conveyers, dryers, screen sorters), a larger and more complex gasifier, a new CHP module (engine and engine management subsystems and thermal delivery subsystem), a gas bypass system, a rotary-cup-valve air lock feeder, new valve actuators, and a variety of new sensors. The I/O count on the ESTCP system was 136 inputs and 112 outputs, versus a previous maximum I/O count of 112 inputs and 80 outputs.

As part of the drive to build modularity in our designs, the control systems and corresponding control code was split up into separate modules for the front end of the system (feed conditioning system), the main gasification and gas conditioning system, and the back end of the system (CHP system). This first phase of code development involved 28 separate code revisions.

After the first development phase, algorithm testing and system hot testing proceeded in parallel through the end of the first year. During this second phase, CPC operated the system on a daily basis at CPC, upgrading mechanical and electrical subsystems and control code with the goal of enabling the entire system to operate in an automated and unattended fashion. This second phase involved another 22 separate code revisions. A mechanical and electrical punch list was managed on a daily basis to eliminate faults, correct problems and upgrade the capability of the system.

Engine testing also took place. This was the first operation of the engine that we designed uniquely for operation on producer gas. Extensive testing was performed to test power, fuel mixtures, timing, turbo boost, efficiency and emissions. A number of problems were encountered, including excessive oil blow by, backfiring, mixture control, and so forth. However, we were able to confirm that the engine had sufficient power to meet our contractual power goals (75 kW_e), as well as, our commercial goals (100 kW_e net of system parasitics). We soon observed poor compression readings and decided to perform an engine teardown, due to the blow by and low efficiencies we were seeing. This teardown occurred in the first quarter of 2011.

We switched wood chip suppliers to Rocky Top, located in Colorado Springs, so as to be familiar with their feedstock and delivery capabilities, because they were the preferred supplier when operating at Ft. Carson.

The main problem area was the 12-L Eliminator engine (turbocharged with inter-cooler), which had several engine failures. We rebuilt the engine several times. The first failure was caused by a broken lifter bolt that caused backfiring. This was caused by a random material failure of the bolt and was easily detected and corrected. The second failure was caused by poor ring seating caused by an improper ring gap set by the engine manufacturer; this led to excessive blow by and reduced compression. It also caused damage to the pistons themselves. We also found that the camshafts were badly eroded after only a few hours of run time. The ensuing engine-rebuild included piston, ring and (billet) camshaft replacement. We also had to replace seals throughout the engine due to excessive crankcase pressures caused by the poorly seating rings. Subsequent to this rebuild, we lost oil pressure and had to tear down the engine to remove and replace the oil pump due to metal fragments in the oil from the camshaft erosion. By March 21, 2011, the engine was back on line and operating correctly. These problems were not wholly unanticipated given the novelty of the engine design and build, but it did delay engine testing for several months.

While testing continued at CPC, we suffered an engine failure on June 16, 2011. The crankshaft separated into two pieces. We believed that the design pushed the stroke to a length that could not be supported by the throw of the crankshaft journals.

We moved quickly to complete the construction of an alternate engine that had been ordered earlier in the spring to act as a contingency for just such a failure. This alternative engine was made by the same manufacturer, but was not stroked for extra displacement. It was a 9.8-L engine, which should have still given us the required power under this contract (75 kW_e).

The alternate 9.8-L engine (not turbocharged) arrived in mid-July 2011 and was quickly integrated into the existing power generation module. The system and the engine underwent final testing at CPC during the months of July and August 2011. Final power generated was 61 kWe (equivalent to over 75 kW_e corrected for standard atmospheric conditions) with a final thermal output of 85 kW_{th}. This was less than hoped for given the overall system was designed for 100 kWe, but sufficient to meet this project's electrical design objectives.

We completed system testing at CPC, shipped, and installed the system at Fort Carson in August 2011. Air emissions test results were submitted for review by Ft. Carson in late August 2011 for the engine's exhaust and for the auxiliary flare, conducted by an independent testing agency at CPC prior to installing the system at Ft. Carson. We then waited on environmental permitting to be completed at Fort Carson, expecting the permit to be forthcoming shortly.

In September 2011, those results were reviewed by the environmental consulting firm working on behalf of Fort Carson, who subsequently established that the Colorado Department of Public Health and Environment (CDPHE) would require a revised Air Pollutant Emission Notice (APEN), due to the flare on our system being a new "control device". This triggered a lengthy review by the state of Colorado, even though the actual measured emissions levels were an order of magnitude lower than the levels that would trigger the review requirement on the basis of emissions alone.

This review process by CDPHE proceeded through the end of the year 2011 without any indication of progress. In the meantime the system was physically locked down and we were prevented from operating the system in any way. The delays in the CDPHE review were caused, in part, by a large backlog of permits due to a 70% jump in permit applications. This CDPHE work load increase came as activity in the oil and gas industry surged with new exploration and tertiary recovery techniques (fracking and so forth).

In the first quarter of 2012, we received permission to operate at Fort Carson. The BioMax® 100 system was working very well, although we slowly cleared faults and made minor software modifications before attempting to transition to 24/7 operation.

The 9.8-L engine was producing about 60 kWe at Ft. Carson's high altitude (this engine was therefore expected to produce 75 kWe @ sea level), which met the minimum power levels of the demonstration, but was far short of the full potential of the gasification system. In addition, the engine was consuming a large amount of oil (approximately one quart for very two hours of run time). The engine was not leaking and the oil replacement was consistent over 20 or more hours of run time, so we believed the oil was, in fact, being burned in the engine. However, there was no evidence of smoke, plug fouling, or other indications of high oil consumption.

During this shakedown testing, the flare was operated more than it would have been under normal operating circumstances. Unfortunately, we had a limited budget of hours to operate the flare (108 hours/year) that was based on our best-case estimate submitted to Fort Carson's environmental consultant. This estimate was incorporated into the environmental permit and the resulting budget was not conservative enough. We used up almost half of the annually allotted flare time in the first six weeks of operation. Although we expected the flare use to drop significantly, as we extended the run time and reduced start-ups (this being when the flare was operated), we would still run out of flare time in a matter of weeks or months and then be shut down under the existing permit.

When we had our original 12-L engine fail in 2011, we embarked on a second developmental effort in parallel to replace the single, large-displacement, custom 9.8-L engine with a pair of smaller commercial engines; these were identical to the 8.1-L GM engine used at another BioMax® System installation site that operated for about 15,000 hours without a failure or major rebuild. We built a replacement Power Generation Module (PGM) to replace the existing one at Fort Carson.

This replacement PGM was internally funded by CPC and was the standard for our commercial product line. After validation testing at CPC and installation at Fort Carson, it should have allowed the Fort Carson system to operate at its full potential (equivalent to 125 kW_e gross power with at least 100 kW_e being delivered to the site at sea level).

In the meantime, CPC took the initiative to find a way to eliminate the flare from future systems. We accomplished this by building in dual-fuel capability to our 8.1-L engine gensets. Initially, we reconfigured these engines with gasoline injectors. With this capability the engines can operate on either gasoline or producer gas, or they can operate on any mixture of the two.

Our previous engine configurations used only producer gas, so the producer gas had to be of sufficiently high energy content to start the engines. This meant that system startup (thermal warm up and initial gasifier operation on hydrogen-depleted charcoal gas) would depend on remote power and the low Btu content gas would be flared until gas quality was normal and the engines were running and generating electricity. With the new dual-fuel capability, we were able to start on fossil fuel and supply power to the system for the warm-up period, which would be necessary for an off-grid application. When the gasifier was lit and came up to temperature on charcoal fuel, this initially weak gas was ingested by the engines, partially offsetting the consumption of fossil fuel. The engines transitioned from a gasoline/weak-producer-gas mixture to be exclusively fueled with producer gas, as the gasification system transitioned to normal operation.

This new design allowed us to eliminate and physically remove the flare by using this dual-fuel capability. The dual-fuel capability and elimination of the flare made the technology more attractive to military customers and other applications, where any open flames are discouraged. It also eliminated all permitting regulations (and operating time budgets) with respect to flare operation at Fort Carson.

We decided, with ESTCP's approval, to replace the faulty 9.8-L engine with a new BioMax® 100 PGM. This PGM used two commercial GM Vortec 8.1-L engine/gensets that had worked well in other applications. Replacing the previous, faulty engine/genset with the dual-fuel, dual-engine design required a new cycle of environmental permitting to approve the new engines; the system was dormant until this permitting cycle had been completed.

The Vortec engines were originally designed for gaseous-fuel operation, but CPC modified the engines by installing relatively small gasoline fuel-injectors, which limited the possible power output of the engine when fueled with gasoline. The small fuel injectors were selected to provide enhanced atomization of the gasoline at the desired low power levels. The typical steady-state output of this 8.1-L engine/genset with gasoline is limited to only about 11.1 shaft kW (**15 hp**) to produce 10 gross kW_e of electricity. When fueled with producer gas, the gross steady-state electrical output per engine can be as high as 55 kW_e, which translates to 78.5 shaft-hp from each engine with the 94% efficient conversion of shaft power to electricity claimed by the generator manufacturer at this power output. CPC added a 3-way catalytic converter to the engines to minimize the emissions of regulated air pollutants.

The design, assembly, testing, and tuning of this replacement module was completed in the second calendar quarter of 2012. Emission testing was completed by an independent testing agency on June 6, 2012, using a lean-burn mode and the CARB 2007 test protocol. The resulting emissions levels, although sufficient for permitting at Fort Carson, were higher than expected.

On July 7, 2012, we were advised by Fort Carson's environmental consultant that, because the engine would be operating on gasoline part time (during gasifier startup), we would be subject to EPA regulations 40 CFR 60 Subpart JJJJ that regulate new source emissions from stationary spark ignited internal combustion engines. So, this source testing had to be done over.

As reported earlier, the dual-fuel capability of the new engine design allows start up to be carried out using a liquid fossil fuel, thus eliminating any need for the flare. A typical gasifier startup sequence lasts about 45 minutes and consumes several gallons of fuel. Startups are infrequent as the system approaches 80% availability during continuous operation. In normal use, we estimate one startup every 200-300 hours.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages The advantages of the CPC BioMax® gasification system are the environmentally benign conversion of waste biomass (woodchips) to heat and power without high byproduct disposal costs. This technology addresses two problems facing DoD facilities:

a) Waste biomass disposal; and
b) Reduction of fossil fuel usage for heat and power.

The advantages of CPC's advanced-state-of-the-art gasification technology are:

a) The negligible level of residual tars in the producer gas that would otherwise require the disposal of accumulated tars as hazardous waste and increased maintenance (conventional gasification systems have a significant amount of residual tars that must be destroyed in a separate catalytic reactor or removed by liquid scrubbing);

b) The clean burning nature of our producer gas appears to extend engine life compared to using liquid fossil fuels

i.(we have operated a "sister" spark-ignited engine fueled with only producer gas made with a similar, but smaller BioMax® 50 gasifier from walnut shells for over 14,500 hours without an overhaul. This compares very favorably with gasoline engines with engine overhauls about every 125,000 miles (equivalent to 2,500 hours at 50 miles per hour) and with diesel engines with recommended engine overhauls every 350,000[6] to 375,000[7] miles, equivalent to 7,000 to 7,500 hours at 50 mph.);

c) The lack of a condensed water by-product, which would require expensive treatment prior to disposal;
d) The automation that permits safe, unattended operation to minimize labor costs; and
e) The self-dumping gasifier grate, the two char-removing subsystems, and the self-cleaning filters that extend the periods of operation between routine maintenance, which decrease the time required for maintenance.

The advantages of the BioMax® systems' modularity are:

a) Quick commissioning – only a few months pass between receipt of an order to the system being commissioned on site, improving cash flow issues and economic viability;
b) Minimal environmental impact – system is intended for relatively small scale distributed heat and power applications, which minimizes the local environmental impacts and makes them easier to permit;
c) Parallel installation – multiple systems can be installed in parallel to permit better load following;
d) Self-contained – systems need no new facilities to house them; and
e) Easy to re-deploy to a new site.

Disadvantages Current limitations of this new technology are:

a) A low number of operational hours in the field with wood chips at this scale;
b) High capital cost because prototype units are not yet benefitting from the economies of mass production; and
c) The need to dry many biomass feedstocks to below 18% moisture content (wet basis) requires extra equipment (drier) to accomplish, which increases the capital and operating costs for that particular feedstock.

3.0 PERFORMANCE OBJECTIVES

Table 1 shows the performance objectives for this project. The following text describes these objectives in more detail. The results of this demonstration are discussed in detail later in Section 6.0 Performance Assessment.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Carbon Footprint Reduction	Tons CO_2 per year and tons/MWhr	CO_2 emissions of fossil fuel generators and BioMax® used to produce electricity and heat; kW of delivered heat and power	300 Ton CO2/MWhr [8]	Fossil CO_2 emissions only briefly during system startup; projected displacement of 0.912 ton of fossil CO_2/MW_eh
Payback	Years to payback	System efficiencies, availability, energy costs and usage, capital and recurring costs	>7-year payback as per NIST Building Life Cycle Cost Program	Need high energy costs to meet this goal
Drier Performance	Moisture content and throughput	Feedstock weight and moisture measurements	Dry feedstock to less than 18% moisture (wet basis). Ability to successfully gasify dried feed	Feedstock did not need much drying, so drying not well demonstrated; gasifier worked well
Producer Gas Quality	Lower Heating Value of gas; tar and particulates	Producer gas composition; CPC's tar and particulate protocol	>115 Btu/SCF <25 ppm tars <10 ppm particulates Long life of filter media and clean engine intake valves	135 Btu/SCF ➢ Tars were not operational problems
Operational Availability	% of time system is operational	Monthly Operational Log	>80%	Was steadily increasing to end at 74%

Ease of Use	Number of operators, skill level and training requirements	Time of assisted operation, operational support requirements, factory support requirements	One operator trained and maintaining required availability within one month after field commissioning	Trained operator supplied by CPC, but not able to achieve desired availability
Reliability of BioMax® system Technology	Maintenance requirements, Mean Time Between Failure, Mean Time to Repair	Documentation of maintenance, failures causing system shutdown and repairs	Maintenance < 3 days/month MTBF > 21 days MTTR < 2 days	Last month of demo: MTBF = 4.33 days MTTR = 0.27 days
Gross Power and Heat Production	kW_e; kW_{th}	Electrical power meter; Hot water temperature and flow rate	>100 kW_e >500,000 Btu/hr (150 kW_{th}) thermal	Achieved 83kW_e at 5830 ft. elevation, extrap. to 100 kW_e at sea level
Emissions Quality	lbs/MWh of combined heat and power	Engine exhaust gas analysis for CO, NOx, THC emissions; exhaust gas flow rate	CARB 2007 for waste gas <0.5 lb NOx/MWh <6.0 lb CO/MWh <1.0 lb VOC/MWh	0.49 lb NOx/MWh 0.20 lb CO/MWh 0.013 lb VOC/MWh
Qualitative Performance Objectives				
Bio-Char Quality and Usage	Elemental analyses of bio-char and its leachate	Heavy metal analysis, TCLP	EPA TCLP Non-Hazardous Designation for disposal	No toxic levels of heavy metals. Only some benzene in Filter Char leachate

Carbon Footprint Reduction Because biomass represents stored solar energy using relatively contemporary carbon dioxide (compared to fossil fuels), the gasification and combustion of biomass is considered to be carbon neutral (or slightly negative to the extent that residual carbon in the solid wastes is sequestered back into the soil). Conversion efficiencies used to generate electricity and heat at the DoD facility and tons of carbon dioxide released per MWh of electricity and of heat delivered were calculated for existing fossil fuel based technologies and compared with the BioMax® system. These site specific figures of merit were used to determine the amount of atmospheric CO2 reduction achieved by the operation of the BioMax® system.

Payback An economic model was developed using NIST's Building Life Cycle Program (MILCON Analysis for Energy Project) to allow general inputs of system availability and the efficiencies of the gasifier, engine/genset, and waste-heat recovery, as well as, site specific inputs of feedstock cost, electricity, and heat to the DoD facility, the ability of the facility to utilize that electricity and heat generated, and the value of the byproduct bio-char as a fertilizer (or its disposal cost). Outputs included payback periods and how selected variables interact. The goal of this model was to assist in identifying DoD facilities that would most benefit from the deployment of the BioMax® technology.

Bio-Char Quality and Usage The only significant byproduct from the BioMax® gasification systems is a small amount of char made from the biomass. This char contains carbonaceous residues and the mineral nutrients that were present in the feedstock. Recently there has been considerable interest in using charcoal to sequester carbon and to improve the fertility of the land. Char generated during the field demonstration was tested for its suitability for use as a soil amendment or fertilizer, using standard EPA tests for heavy metals, leachate tests (TCLP), etc. The goal of this testing was to confirm previous findings by the States of Colorado and California that char made from biomass with the BioMax® system is a non-hazardous waste and suitable for use as a soil amendment. Fortunately, many states follow the Federal EPA guidelines, but each site must comply with the local environmental regulations.

Drier Performance The BioMax® drier uses recovered waste heat in the form of heated air from the producer-gas cooler to dry the raw, wet feedstock. It is critically important that the drier be able to adequately dry the as-delivered raw feedstock for continuous system operation to avoid the extra cost of purchasing drier feedstocks. Samples of the raw feedstock and of the dried feedstock were taken periodically to verify the adequacy of the drying system using recovered waste heat to produce a dried feedstock.

Producer Gas Quality The lower heating value and the levels of residual tars and particulates determine the quality and usefulness of the producer gas. During testing at CPC, these parameters were determined to verify that the larger, scaledup gasifier was performing well (see section 2.2 Technology Development for details of the scale up). The levels of carbon monoxide, hydrogen, methane, carbon dioxide, and oxygen were measured using a NOVA gas analyzer. The gas composition was used to calculate the heating value of the producer gas. Low tar and particulate levels in this clean producer gas were demonstrated by the measured extremely low levels of difficult to burn tarry VOC's and particulates in the engine exhaust gases and trouble-free engine intake valves.

Operational Availability To have the maximum beneficial presence in the field, the BioMax® system must be operated on a continuous 24/7 basis with a minimal amount of down time for maintenance and repair. Previous CPC experience has shown that after the first few months of the deployment of a new system, monthly operational availability can average over 80%. A log of gasifier operational time and of down time was maintained to establish the monthly availability of this new BioMax® system. The goal was to maximize the operational availability to over 80%, but an availability of 74% was reached prior to the end of the field demonstration.

Ease of Use BioMax® systems are fully automated, allowing for unattended operation. This automation is internet connected, allowing the operator to monitor and control the system remotely, i.e., from home with a computer or with a hand-held internet-connected device. Periodically, the system must be shut down for routine maintenance. Minimizing the elapsed time required for this maintenance has been the design goal of many of the recent system innovations. As intended, one part-time person operated and maintained this entire gasification system, after the initial period of system setup and shakedown in the field.

Reliability of Technology The reliability of the technology is measured by the mean time between maintenance or repair of the many subsystems of the BioMax® system that require shutting down the system. A log was maintained of every component failure or subsystem requiring maintenance to determine the robustness of the system and to identify subsystems in need of improvement. Continuous gasifier operation for over 21 days between system maintenance is needed to achieve the availability and ease-of-use objectives. However, we were only able to achieve up to 4.2 days on continuous operation this new system. Most of the problems that interrupted operations were quickly resolved, resulting in a close approach to the goal of 80% reliability.

Net Power and Heat Production The goal was to produce the maximum amount of net power and recovered waste heat from the BioMax® 100 system, which will minimize the payback period and maximize the economic benefit. The net power exported from the system was monitored with a power meter in terms of kW_eh. The recovered waste heat in kW_{th} was calculated from the flow rate of hot water used to deliver the heat to the client and the change in temperature of the water as it passes through the CHP heat exchanger. The goal was to deliver over 100 kW_e and 150 kW_{th} (500,000 Btu/hr). These goals were exceeded with a delivery of a net 83 kW_e to the grid and 180 kW_{th} for building space heating at the high altitude of Fort Carson.

Emissions Quality It is imperative that the system operate in an environmentally benign manner with minimal emissions of NO_x, CO, and hydrocarbons. The Federal regulations in 40 CFR Part 60 mandate a certain test protocol to use to measure engine exhaust emissions and the allowable emission levels.

In general, the states use this Federal mandate as a guide for their own locally allowable emissions, although some states, e.g., California, have mandated a different test protocol and lower allowable levels of these emissions from distributed power systems. However, local air quality boards in California can and do allow emission levels in excess of the California state standards.

We have adopted the goal of meeting the more universal Federal regulations for gaseous emissions from internal-combustion engines. To measure these low levels of emissions accurately requires specialized equipment, best maintained by a dedicated outside subcontractor. We employed the services of an environmental testing contractor at CPC, prior to the commissioning process in the field. The emissions are expressed as grams of pollutant per horsepower-hour, g/hp-hr of shaft power, for comparison to the Federal EPA standard found in 40 CFR Part 60 JJJJ.

4.0 FACILITY/SITE DESCRIPTION

Fort Carson was selected to host the demonstration of the BioMax® 100 system. The unit was installed on the north side of Building 8030. It provided electricity to Fort Carson's distribution grid and heat for the seasonal space heating load of the building. Use of the recovered heat in the warmer months of the year could be to make hot water or to power an absorptive cooling system, but this was outside the scope of this demonstration.

Facility/Site Selection

The criteria for site selection included:

1) Reliable sources of up to 300 tons of woodchips over the 6-month demonstration period, either from the facility's grounds or from within an economical distance for reliable delivery from multiple local sources. Ideally, this would be a site having surplus woody biomass that is already being chipped and disposed in an expensive manner, e.g., by landfilling;

2) A facility that has a strong dedication to reducing fossil-fuel use, preferably located where both grid electricity and heating fuels are expensive, thus providing strong economic incentive to the facility to support this demonstration that will deliver heat and electrical power;

3) A location having a long cold season, requiring significant building heating to make the capture of waste heat more valuable and advantageous to the host site;

4) A facility that is easily accessible by CPC personnel for their support roles in the field demonstration;

5) A location that is not having severe air quality issues that would make air permitting overly restrictive or onerous; and

6) A location near a population center from which it is reasonable to expect to be able to hire a suitable technician to train to operate the BioMax® system.

Sandia National Laboratory (SNL) was given the responsibility in this project to survey DoD facilities for the potential siting of BioMax® systems. SNL compiled a list of 170 potential DoD sites with the contact information, apparent interest in alternative energy, size of the facility in acres, local sustainable biomass resource available in the local county area, and the local cost of electricity and of heating fuels.

SNL compiled four lists, based on:

a) A combination of perceived receptiveness to hosting a BioMax® system, and the amount of woody biomass resource available on the facility;
b) The facilities with the largest biomass resource base with access to over 100,000 tons/year of woody biomass (including urban wood waste) within a 25-mile radius; and
c) Proximity to CPC for ease of technically supporting the field demonstration effort.[9]

Figure 6 shows that there were a large number of DoD facilities that could support not just one, but a large number of BioMax® 100 systems with their own or local biomass resources. There has been effective motivation within DoD facilities to reduce power consumption and to search for alternative energy sources, so good command support for the demonstration appeared to be widespread and available. Not all of the sites had a long cold season, but they all reported heating water and were therefore candidates for using the recovered waste heat. For example, large amounts of heated water are used for seasonal space heating and year around by laundries, swimming pools, adsorption cooling, etc. Although this study used a feedstock basis of $40/ton, the actual cost can vary between $35 to over $100/dry ton in the U.S., depending upon the local market.

The summary report for the feedstock study is attached as Appendix B.

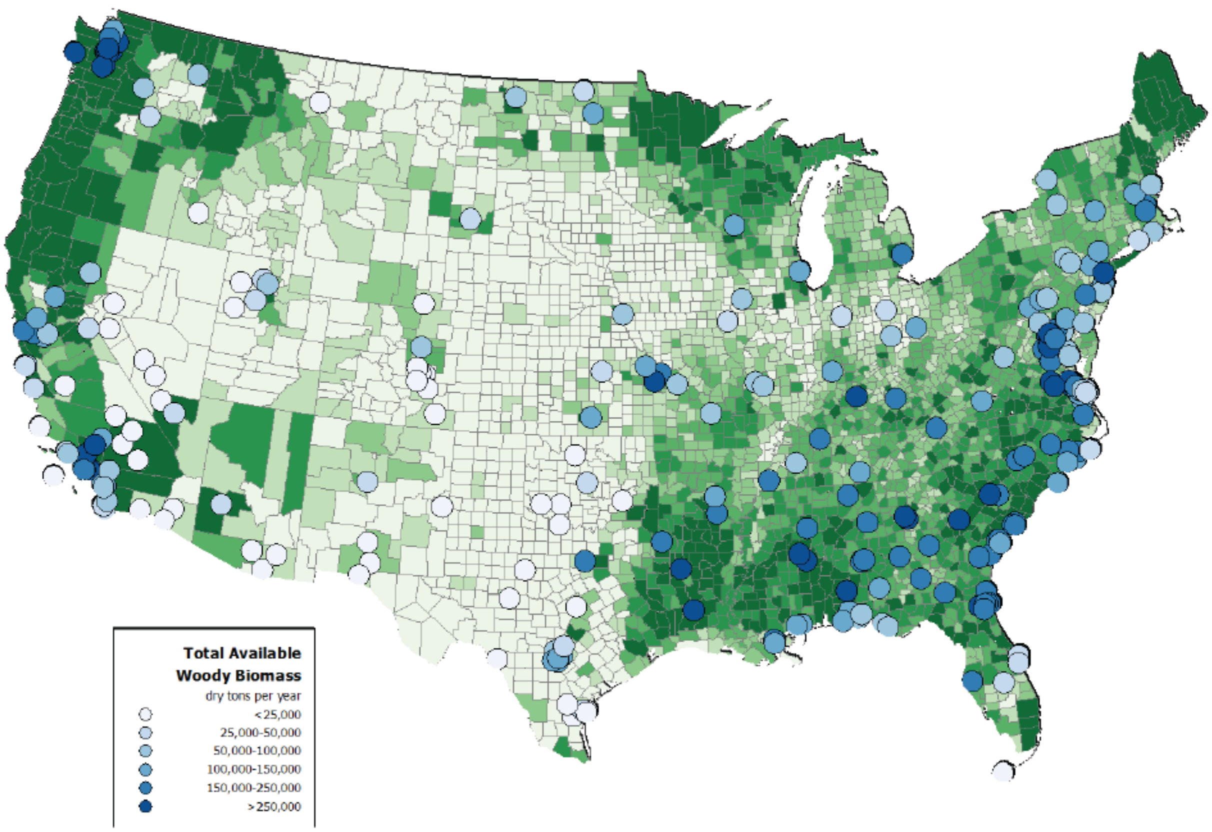


Figure 6. Available Woody Biomass for Under $50/ton at Military Installations

The high cost of electricity and liquid heating fuels at DoD facilities on the Pacific islands caught our attention. Although the cost of electricity and heating fuel would be important drivers for prioritizing the deployment of future BioMax® systems, the actual cost savings generated during the demonstration were recognized as being secondary in this project to the ability of CPC to rapidly provide technical and material support to maximize system availability during the demonstration. In particular, operational data from the demonstration could be used to extrapolate future operating costs at any potential DoD site. Consequently, finding a host site in close proximity to CPC became very important to the site selection.

Two DoD facilities close to CPC were judged to be outstanding:

1) The United States Air Force Academy (USAFA) at Colorado Springs; and
2) The Army's Fort Carson at Colorado Springs.

Based on facility visits in Colorado and discussions with representatives of DoD installations in Hawaii, CPC initially selected the US Air Force Academy (USAFA) as the proposed host facility for the ACE BioMax® demonstration project. Sites in Hawaii were originally of interest due to the high energy costs there, but the logistics of supporting a new, untried system in the field were judged to not offset their higher project cost, relative to the project's objectives. Due to various issues raised by USAFA personnel (primarily objections to the visibility of the containerized BioMax® system), no final site could be agreed upon at USAFA, so CPC chose to switch the demonstration project to Fort Carson.

4.1 FACILITY LOCATION AND OPERATIONS

Fort Carson is located approximately one-hour south of CPC's headquarters, just south of Colorado Springs, Colorado, east of the Rocky Mountain Front Range, and occupies portions of El Paso, Pueblo, and Fremont counties. Fort Carson is generally bounded by State Highway 115 on the west and by Interstate 25 and mixed development on the east. The City of Pueblo lies approximately 10 miles south of Fort Carson's southern boundary. The City of Fountain is located east of Fort Carson.

Fort Carson comprises approximately 137,000 acres and ranges from 2 to 15 miles from east to west and up to 24 miles from north to south.

Soldier support facilities are provided in the cantonment area, which contains most of the facilities on Fort Carson such as troop and family housing, and administrative, maintenance, community support, recreation, classroom, supply, and storage facilities. The BioMax® unit was demonstrated in this area.

Fort Carson's training mission is primarily executed at downrange training areas used for weapons qualification and field training. The downrange area comprises the land area outside the cantonment area, including firing ranges, training areas, and impact areas. Training lands at Fort Carson are actively managed to maintain sustainability of the area for continued use in supporting the Army's training mission.

Figure 7 shows a rough outline of Fort Carson's boundaries, with the cantonment area located along the northern boundary of the installation, where the BioMax® 100 was located. Figure 6 shows the demonstration site on Fort Carson, at Building 8030 and the route from the main gate.

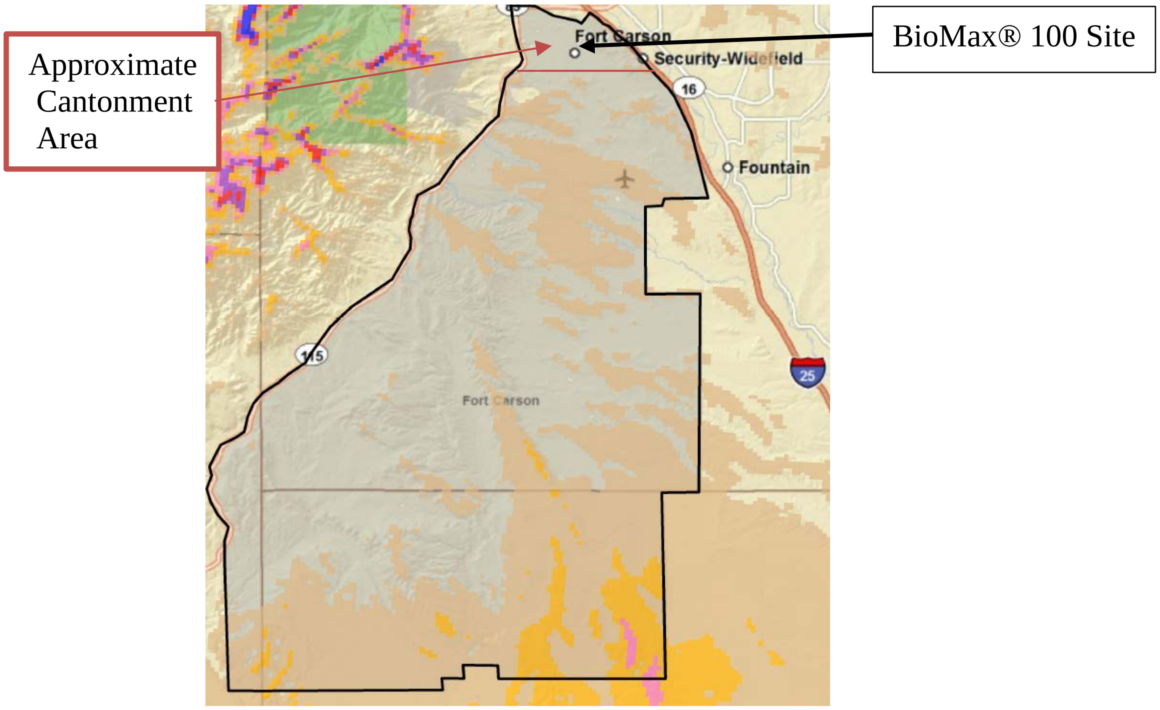


Figure 7. Fort Carson Installation Boundaries

The site selected at Fort Carson is on the north side of Building 8030, on the corner of O'Connell Blvd and Armory Rd. We delivered the electrical output of the system to their grid, as well as, drew small amounts of power during maintenance periods when our system is shut down. Building 8030 is a vehicle and equipment maintenance building. This site had very good access for electrical tie-in, no interference with access or parking, and a large work bay that was flooded with hot air from the system during the winter months. Furthermore the building was surrounded by concrete surfaces, so no foundations would be required for siting the BioMax® system. Two fan-coils were installed in the maintenance bay of the Building 8030, adjacent to the BioMax®, along with pumps, expansion tank, valves, automatic air vents and pressure relief valve.

Figure 8. Location of Demonstration Site at Building 8030

4.2 FACILITY/SITE CONDITIONS

The climate at Fort Carson is a combination of Great Plains weather with severe winter weather coming down from Canada and Rocky Mountain weather with winter storms primarily from the Pacific Ocean. Summers are relatively mild and short, with day-time high temperatures seldom above 95°F. The humidity in this semi-arid climate is relatively low, which contributes to low moisture contents occurring naturally in biomass feedstocks.

The altitude at the Fort Carson cantonment is about 5,830 ft. above sea level, with an average barometric pressure of about 11.9 psia, compared to sea level with 14.7 psia. This high altitude results in lower engine performance due to this lower barometric pressure. This lower engine performance is due to the lower energy per volume of fuel/air mixture that can be pulled into the engine by each stroke of the pistons.

CPC and Fort Carson's Directorate of Public Works (DPW) staff met several times to discuss the demonstration project. Multiple sites were considered and the Building 8030 site was selected as optimal for several reasons. Delivery trucks were able to use perimeter roads, minimizing disruption in the cantonment area. Additionally, the building's space heating requirements provided a seasonal heat load for the system.

Although the energy that this facility consumes is relatively low cost electricity ($0.060/kWh) and natural gas (likely less than $6.00/MMBtu) and would not normally be chosen to

demonstrate a large energy cost savings, it is located within an hour's drive from CPC's headquarters for cost-effective field support during the demonstration. The energy savings demonstrated in this project are expressed in kW_eh and MMBtu/hr, which can be easily translated into site specific cost savings for valid economic evaluations at all other DoD sites using their local site-specific energy costs.

The primary point of contact for Fort Carson was Vince Guthrie, DPW Utility Programs Manager. Mr. Guthrie was an active participant in the site selection process and coordinated a visit by several other Fort Carson DPW staff to observe the BioMax® unit in operation at CPC's headquarters on April 28th, 2011.

<u>Site-Related Permits and Regulations</u>

The Colorado Department of Public Health and Environment has previously ruled that the by-product char made from woody biomass is a non-hazardous waste for disposal purposes.[10] During the six-month demonstration, we performed EPA's TCLP test on the recovered char to determine if the non-hazardous classification has changed during the intervening several years of gasifier development. The results of these tests are discussed in Section 6.0 Performance Assessment.

CPC worked with the Environmental Protection group and their environmental consultant at Fort Carson (Sara Lubchenco-Burson of HDR Environmental, Operations, and Construction, Inc.) and the Air Pollution Control Division of the Colorado Department of Public Health and Environment (CDPHE) to apply for air-emission construction and operating permits. It appeared that the projected emissions of the BioMax® 100 by themselves would be an order of magnitude too small to require an operating permit from the state of Colorado. [11,12]

However, the BioMax® emissions would contribute to the overall Ft. Carson emissions. Prior to commissioning of the BioMax® 100 at Fort Carson, an outside environmental testing company measured the exhaust emissions at CPC. Consequently, after the engine-exhaust emissions from the BioMax® system were measured by a third party, an Air Pollution Emission Notice (APEN) was filed with CDHPE for approval prior to operation. This permitting procedure was repeated after the first engine failed at Ft. Carson and had to be replaced with two smaller engine/gensets. Obtaining permission to operate led to significant program delays on both occasions.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The baseline testing at CPC was designed to provide quantitative data on the performance of the BioMax® 100 system that are needed to determine the technical and economic viability of the technology. These data were necessary for the valid comparison and prioritization of applicable alternative energy concepts, when making deployment decisions.

The Demonstration test period commenced at Fort Carson after the installation of the BioMax® 100 system at Fort Carson in August 2011. CPC's interpretation of the Colorado regulations was that the BioMax® 100 was too small a pollution source to require permitting in Colorado. However, the environmental group at Fort Carson determined that the system would need to be permitted by the state of Colorado, before it could be operated at Fort Carson. This permitting process delayed the commissioning for six months until February 2, 2012..

The Commissioning period lasted until the system was grid tied, and the system debugged and operable. The delivery of electricity to the grid first occurred on March 7, 2012. The system was operable, but still required the presence of a full-time operator due to a combination of problems with the control code and mechanical problems.

The Controlled Testing period began immediately after Commissioning was completed. It involved daily attended operation until the re-assembled, automated system completed at least 24 hours of operation with no operator intervention required. The first run of around-the-clock system operation at Fort Carson occurred during the period of April 24 through 25, 2012 for about 41½ hours, but with an operator present at all times. At this time, the 9.2-L engine was using excessive quantities of oil and the testing halted until the engine could be replaced. A replacement module of two 8.1-L Vortec engines was developed at CPC to use gasoline during system startup and then to switch to producer gas, eliminating the need for a flare at startup. These engines were tested for emissions at CPC with producer gas first on June 6, 2012. After submitting the results to Ft. Carson for review, the engines were tested at CPC for emissions from gasoline and then from producer gas on August 7, 2012. These emission results were submitted to Ft. Carson and the State of Colorado, resulting in a new permit to construct and operate that was issued three months later on November 28, 2012. Removal of the old Power Production Module and installation of the new one was completed in January 2013, with hot shakedown of the final BioMax system configuration starting on February 11, 2013. Reliable operation of the new system was attained in the latter part of May 2013.

The Operation period began after the successful completion of the Controlled Testing in the latter part of May to the end of July 2013. The on-site presence of the operators was decreased until remote monitoring and operation were the norm. The reliability and ease of operation steadily increased during the last three months of operation, as minor adjustments and improvements were made to the system.

Initial plans for the feedstock supply were to enter into a long term contract with a Colorado based supplier, Renewable Fiber. Renewable Fiber confirmed that they could deliver the

required supply of woodchips from pine-beetle-kill thinning efforts in Colorado local to the region where Fort Carson is situated. CPC utilized a walking floor trailer to feed the system, which contained approximately 150 yds^3 of material or a 4 day continuous supply. When the trailer was emptied, it was taken to the feedstock supplier for replenishment. The delivered cost of these woodchips was \$14.50 /yd^3, which corresponds to \$119 /dry ton of biomass, assuming an average moisture content of 18% and a bulk density of 11 lbs/ft^3 (measured on other Colorado softwood chips). This high feedstock cost reflects a lack of local competition and small volume purchases and is not representative of CPC's experiences at other BioMax® operating sites.

Data was automatically logged by the computer that also controls the BioMax® system. From these data are calculated the producer gas flow rate, gross power produced, and parasitic power consumed every minute. Most of these data were used to verify that the modules were all operating properly and to predict when maintenance will be required for acceptable operation.

Only a few of these data had significance to the technical and economic evaluation of the BioMax® 100 system. For example, the total hours of operation, time between maintenance or failures, percent availability, and total kW_eh, and $kW_{th}h$ delivered were all summarized at the end of each month. These parameters are presented as a function of time to reflect the benefits of experience gained and expected improvements made to the system during the field demonstration.

Only a small amount of specialized data or information was manually logged, e.g., maintenance required, time of subsystem failures, labor required for maintenance and repair, consumables expended, etc. Summaries of the automatically and manually logged data of interest are reported in this final report.

5.2 BASELINE CHARACTERIZATION

Fort Carson Test Location

The baseline characterization of Building 8030 was not necessary to determine, because CPC directly measured the electrical and thermal energy delivered by the BioMax® 100 system. All of this delivered energy displaced grid electricity and natural gas that would otherwise be consumed. Whether or not the facility saw a decrease in their fossil-fuel derived utilities depended heavily upon factors outside of our control, e.g., the weather and the energy conservation behavior of the facilities manager.

Thus, we did not need to make questionable estimates of the energy that would have been consumed without the presence of the BioMax® system, based on trying to take into account the severity of the weather or changes in facility operation during the demonstration period, which we would need to do if we could not directly measure the net energy delivered.

We were very certain that the year around base load of electricity at Fort Carson is several orders of magnitude more than that produced by the BioMax® 100 system. After measuring the recovered waste energy, the BioMax® 100 was designed to automatically release any unused recovered waste heat as hot air to avoid overheating the engine.

BioMax® 100 System Testing at CPC

Engine-exhaust emissions were measured by AIRTECH Environmental Services, Inc., on August 7, 2012 at CPC, with the new 8.1-L, Vortec, spark-ignited, internal combustion engines. Measurements were obtained while at steady-state "rich-burn" conditions, fueling first with commercial gasoline and then later just with producer gas from the BioMax® gasifier being fed softwood chips. The test protocols used were those specified by 40 CFR Part 60 JJJJ and other Federal regulations.

The emission results are summarized in the Table 2 and compared to the existing Federal regulations and currently permitted emissions. Table 2 shows the total engine-exhaust emissions from two 8.1-L Vortec engines fueled with gasoline on 8/7/12 with an average of 0.05% oxygen in the exhaust gases (assuming 1 hr/start, 1 start/day, 365 day/yr).

Comparing these measured values to those allowed by 40 CFR Part 60 JJJJ in Table 2 shows that the emissions from the CPC-modified engines are orders of magnitude less than the maximum allowable emissions levels in the JJJJ regulations for New Stationary Emission Sources when burning gasoline, which defer to 40 CFR Part 1054 Table 1 due to the small power level attainable with gasoline.

Table 2. BioMax® 100 Dual-Engine Exhaust Emissions Fueled with Gasoline (8/7/12)

Units	**PM**	**NO_x**	**SO_2**	**THC**	**CO**
ppmdv (0.05% O_2)	NA	13.3	<0.2	3.14	10.4
lb/hr	0.000146	0.01214	<0.000254	0.00274	0.00576
ton/year	0.000026	0.00222	<0.000046	0.00050	0.00106
g/hp-hr	**0.00223**	**0.185**	**<0.00384**	**0.0418**	**0.0876**
40 CFR Part 1054 Table 1 g/hp-hr	**NA**	**8 (incl. THC)**	**NA**	**8 (Incl. NO_x)**	**610**

Producer-Gas Fueled Engine Exhaust Emissions

In addition to testing while operating on gasoline fuel, the exhaust emissions were measured from one 8.1-L Vortec engine fueled with producer gas and producing 50 kW gross of electricity. Based on these emission values, Table 3 shows the total emissions expected from operating the **two** engines simultaneously to produce a total of 100 kW_e gross during 24 hrs/day and 365 days/yr. The measured oxygen content averaged 0.03%, but the emission concentrations are corrected to the standard 15% oxygen concentration for comparison purposes.

There is apparently no category specifically for producer gas in the Federal regulations for the Emissions of New Stationary Sources (40 CFR 40 Part 60 JJJJ). It is assumed that producer gas will be viewed as a fuel in the same category as natural gas. The limits in 40 CFR Part 60 JJJJ Table 1 (after 1/1/2011) for non-emergency engines fueled with natural gas for lean-burn engines producing between 100 and 500 hp are:

a) 1 g NOx/hp-hr;
b) 0.7 g VOC/hp-hr; and
c) 2 g CO/hp-hr.

Table 3. BioMax® 100 Emissions in Dual Engines with Producer Gas (8/7/12)

Units	**PM**	**NO_x**	**SO_2**	**VOC**	**CO**
ppmdv (15 % O_2)	NA	25.9	2.32	0.717	17.9
lb/hr	0.00058	0.1412	0.0178	0.00366	0.0582
ton/year	0.00254	0.6184	0.0780	0.01603	0.2549
g/hp-hr	0.00185	0.449	0.0566	0.0117	0.185
40 CFR Part 60 JJJJ Table 1 g/hp-hr	NA	1.0	NA	0.7	2.0

Table 3 shows that the emission data for the BioMax® 100 engines operated in lean-burn mode with producer gas easily meet this requirement while using producer gas, with:

a) 0.449 g NO_x/hp-hr
b) 0.0117 g VOC / hp-hr; and
c) 0.185 g CO / hp-hr.

Alternatively, the allowable upper limits in the exhaust gas (corrected to 15% oxygen on a dry basis in Table 1 of 40 CFT Part 60 JJJJ) are

a) 82 ppmdv NO_x;
b) 270 ppmdv CO; and
c) 60 ppmdv VOC.

It is seen from Table 3 that the measured emissions were well below these volumetric limits for New Stationary Emission Sources.

The engine-exhaust stack emissions testing results were forwarded to Fort Carson's environmental consultant and appended to the revised environmental permit application that was initially submitted in June 2012. At the end of September 2012, the draft permit was received by Fort Carson and subsequently resubmitted to the Colorado Department of Health and Environment (CDPHE) with final comments.

Baseline characterization was established during testing at CPC, due to the availability at CPC of more instrumentation and personnel than in the field. The Baseline testing was performed using

the same source of woodchips as to be used at Fort Carson, after the initial shakedown of the new system and it was operating properly.

Tests that were not repeated in the field demonstration include:

a) Analyses of the producer gas composition, including tar and particulate levels; and
b) Feedstock consumption rate as a function of producer-gas flow rate.

While we waited on emissions results and permitting for Ft. Carson to move forward, the new engine design was deployed with another BioMax® 100 system at a low elevation in Manitoba, Canada. There it produced up to 130 kW_e (gross), while delivering 117 kW_e on grid. Performance was excellent using wood chips, with no engine oil consumption and with very quiet operation.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The BioMax® 100 system is housed in five 20' ISO shipping containers that serve both as the shipping containers and as the housing for the system while operating on site. After the five modules arrived on site and were correctly positioned, they were rapidly interconnected with convenient multi-channel electrical plugs and sanitary tube fittings. This assured that the correct wiring connections were re-made in the field without using a skilled electronics technician and going through the lengthy Quality Assurance testing required after fabrication at CPC.

Woodchips were delivered in a walking-floor trailer. The trailer was left on site to slowly off-load itself on demand, with its hydraulically operated moving floor using system generated power. We required a bit less than two woodchip deliveries per week, when operating 24/7 at full power. The woodchips fall off the back end of the trailer into a trough, from which they were conveyed into the dryer.

From the dryer, the dried chips were sorted to remove the excessively fine and coarse chips before the usable chips are fed into the gasifier. The fine material typically contained a lot of dirt and is landfilled or better used for composting. The coarse chips could be re-chipped if they were in sufficient quantity to economically justify this extra step. These unwanted materials should have been removed primarily by the woodchip supplier, minimizing the amount of out-of-specification materials for disposal or re-work.

After gasification, the producer gas and char fines passed through the heat exchanger to cool and then were filtered to remove the particulates. The cool, clean producer gas was then used to fuel the spark-ignited engines to power the generator. Waste heat was recovered from the engine coolant and the engine-exhaust gases and was available as hot water.

The BioMax® 100 system is completely automated to allow for unattended safe operation. The computer controls were programmed to respond correctly (in the same manner as a constantly alert expert operator) to broken sensors, variable moisture contents in the feedstock, temperatures too high or too low, abnormal pressures, stalled engine, etc. In the event that the controls are unable to keep the system within established limits of operation, the system will safely shut itself

down automatically. These features are all necessary to attain the unattended operation necessary to minimize the labor required to operate the system.

From the Control Module, the process is controlled by a permanently installed computer, which is connected to the Internet.   The operator can display the measured variables, change control settings, or switch to manual control from a mobile laptop computer onsite using a “Wi-Fi” connection, or while offsite using a computer or personal digital assistant (PDA) via the Internet or other connection. The BioMax® 100 control system alerted the operator when the system had variables whose values are outside of acceptable limits via audible alarms and lights, email, or telephone text message.

The final 250 variables of operational data were logged once about every 15 seconds and stored in the control computer’s memory, from which they can be accessed and downloaded over the Internet through an ftp address. These data files can be readily converted to Excel files to produce charts by the operator or by staff at CPC’s headquarters. The operator’s log with its alarm information and operator’s comments can also be remotely accessed and downloaded.

5.4 OPERATIONAL TESTING

Commissioning

After the Baseline Characterization of the BioMax® 100 system at CPC and the host site for the demonstration was prepared, the system was trucked to Fort Carson, unloaded, and the modules re-assembled and interconnected. The engine/genset was connected to the local electrical grid. Installing a building’s hot-water system to utilize the recovered waste energy in Building 8030 was delayed until late in the Operational Testing. All subsystems were carefully tested to verify that they were fully operational after re-assembly, e.g., woodchip delivery from the chip trailer to the dryer, woodchip dryer, sorter, feeder, gasifier, char removal, gas cleanup, engine/genset, electrical generation, grid connect, and waste-heat recovery and delivery.   The logged data was reviewed to ascertain that all sensors were operational and reporting correctly. This testing was done initially with the system cold and then during short periods of a few hours per day of hot, integrated operation.

The air emissions application, initially submitted in June 2012, was not approved by the State of Colorado until December 2012, almost 6 months later. Very little progress was made in the last quarter, because we were prohibited from completing the planned upgrades until the permit was received.

Following receipt of the permit, CPC’s installation crew immediately started on the system upgrades, removing the previous PGM and installing the new dual engine PGM. A number of controls and wiring upgrades accompanied the installation of the new PGM and we also took the opportunity to remove and replace a feed auger conveyer with a belt conveyer replacement to enhance reliability.

No follow up source testing was required under our Colorado air emissions permit. We needed only to track engine hours on gasoline and on producer gas and report them quarterly to Ft. Carson.

A purchase request was placed with Olson Plumbing on February 26, 2013 for the completion of the plumbing work associated with the installation of the CHP system. Two fan-coils were installed in the maintenance bay of the building adjacent to the BioMax®, along with pumps, expansion tank, valves, automatic air vents and pressure relief valve. The plumbing and associated electrical work was completed in early March of 2013. CPC had to upgrade the 120/208 VAC step-down transformer in order to supply power to the fan coil loads.

The heat was collected from the engines from two heat exchangers, one on the engine exhaust and one on the engine block cooling systems. Capturing the waste heat and diverting it to productive use in this way increases the efficiency of the system (gas energy to useful energy products).

Debug and commissioning followed the plumbing installation and the system went into shakedown testing with the engines being brought on line on February 1st, triggering a notice requirement per the State issued environmental permit. In February, total run time on both engines was 80.7 hours. During this time testing was largely confined to bringing all subsystems on line.

Controlled Testing

The system was operated for an extended period to ascertain that it was operating up to the full baseline output levels with progressively longer durations of operation each day. This initial period of controlled testing was necessary to verify that no components were weakened or damaged by tear-down, transporting the system to its new location, and re-assembly. In addition, with this new system, many of the components were new and their reliability individually and as part of a system was unknown. System modifications were made as needed to achieve the program goals. During the Controlled Testing period, the operators reviewed the logged data to verify that the system was meeting the design goals and functioning correctly. The BioMax® 100 was operated attended 24 hours/day until it achieved sustainable continuous operation in excess of 24 hours without requiring operator intervention.

Operational Testing

After the Controlled Testing was completed, we began: operating the system unattended; monitoring the system from CPC; and attending to any problems that arose on an as-needed basis. These problems, which required the system to automatically shut down or which required maintenance and/or repair, were documented in a permanent log book or file with respect to the date, time of day, total cumulative operational hours, subsystem, the part of the subsystem, what was required to remedy the problem, the number of man-hours involved, and the number of hours of down time that resulted.

The cumulative volume of producer gas and the estimated weight of dry (0% moisture) feedstock consumed were calculated, based on previous measurements and calibrations made at CPC. The operator's log also recorded the cumulative kWh of electricity delivered to the grid, the recovered waste-heat Btu's delivered, the weight of bio-char produced, the weight of charcoal

used at startup, and any filter replacement or other consumable item usage. The engine's exhaust emissions were measured in the Baseline Testing period to verify that environmental permitting requirements were being met.

During the six-month demonstration period, the goal was to operate the BioMax® 100 continuously to accumulate the maximum possible number of hours of availability at high rates of electricity production and waste heat recovery.

Regular system testing started in late March. In March, total run time on both engines was 121 hours. Energy generation for the month was 4967 kW_eh. On March 28th CPC's field engineer hosted a tour of the system by Recharge Magazine as part of a larger media tour of the alternative energy generation technologies at Fort Carson.

Total run time and energy generation for April (3/31-4/27) was 126.3 hrs and 4,590 kW_eh respectively. Availability (19%) and performance were low for two reasons: the system was being run on a daily shift duty cycle (8 hrs/day) and the system struggled with feedstock issues (a malfunctioning feedstock screen sorting system and very dry feedstock). The resulting high fines content and dry feedstock created gasification control issues, including high temperatures and high pressure drops across the bed. Aggressive grate action to try to lower the gasifier bed dP resulted in a grate mechanism failure. The failure was traced to a design problem and the mechanism was replaced. The sorting screen was retuned and the system returned to normal operation.

Total run time for May (4/28-6/1) was 384.4 hrs and energy generation for the month was 21,861 kWhrs. Availability (46%) and performance improved as the operators started to allow the system to run unattended from one day to the next.

In May, the CHP system was finally commissioned following delays in final wiring. It was operated for several days before hot weather prevented further heat delivery into the building. However, the heat load of the building varied considerably. From June 4 to June 7, it was operated at full power for the high altitude at Ft. Carson (90 kW_e gross). During the period of 0800 to 2300 hours on June 5, the CHP system delivered an average of 177 kW_{th} (600,000 Btu/hr) to the vehicle maintenance facility. During this same period, the exhaust gas heat exchanger was reducing the temperature of the exhaust gases from 474°C down to 126°C (884°F to 259°F); Engine #1 coolant's temperature was 82°C (180°F) and that of Engine #2 was 70°C (158°F). The average temperature of the hot water leaving the BioMax® system was 69°C (156°F) and returning was 66°C (151°F), with a water flow rate of 56 m^3/hr (250 gpm).

Total run time for June (6/2-6/29) was 461.6 hrs and energy generation for the month was 26,666 kWhrs. Monthly availability (70%) and performance continued to improve due to consistency in feedstock quality and dedicated O&M support.

Total run time for July (6/30-8/1/13) was 575 hrs and energy generation for the month was 27,862 kWhrs. The longest continuous run lasted 105 hours (about 4.4 days). Monthly availability (74%) and performance continued to improve due to consistency in feedstock quality and dedicated O&M support.

5.5 SAMPLING PROTOCOL

Calibration of Equipment

NOVA Gas Analyzer Model 5-P The NOVA gas analyzer was calibrated using a purchased mixture of the gases, which had been certified by the gas supplier. The calibration was performed at least once every three months, as per the manufacturer, or whenever the operator questioned the displayed results, e.g., lack proper oxygen level during purge cycles with air, or unusual gas compositions being displayed.

AND Infrared Moisture Determination Balance Model 4714A The calibration of the balance and the moisture calculation was verified using reference weights. This was done once at the beginning of the field demonstration.

Thermocouples The accuracy of the temperatures reported by the thermocouples in conjunction with the analog to digital conversion was checked at ambient temperature to verify that the proper type of thermocouples was used, as well as, the proper thermocouple type selected for the electronics converting the signal from analog to digital format. Broken thermocouples report a temperature of 1770°C, which signals their need for replacement. Otherwise the accuracy of the commercial thermocouples is adequate for the purposes of these tests.

Pressure Transducers The zero of the transducers was set for each pressure transducer reading gauge pressure. The span of the transducers was established using a liquid manometer.

Producer-Gas Venturi Flow Meter The producer-gas venturi flow meter was calibrated using the previously zeroed and spanned pressure transducers by comparison to a previously calibrated Reference Orifice meter in series using ambient air as the test gas. The producer-gas flow rate was calculated using the calibrated Venturi-meter, a representative average value of the molecular weight of producer gas, an average local barometric pressure, the pressure relative to atmospheric pressure, and the absolute temperature of the producer gas. The accuracy of the venturi flow meter could be affected by tar or char deposition, but these deposits have not been observed in practice. The venturi calibration was not repeated.

Ohaus Platform Scale Model 5000 This scale was used at CPC to determine the weight of feedstock and bio-char. It had a current certification of accuracy.

BTU Meter The Btu meter that measured the flow rate and temperatures of the hot water being circulated to the building at Fort Carson was made by Onicon, Inc. and calibrated by them using water. This device outputs the value of the heat delivered per hour. A correction factor to this thermal energy value was applied to account for the differences in the density and heat capacity of the water used for the calibration by Onicon and the 50/50 ethylene glyocol antifreeze solution used at Fort Carson, following the calculation method supplied by Onicon to CPC.

During the testing at CPC, the logged data was reviewed for its completeness to generate the operational insights required to meet the objectives of this program. Additional data were taken as determined by the review.

Feedstock At CPC, several grab samples were randomly taken from several locations in the receiving bin at least three inches below the surface of each load of wood chips at least once during each four hours of testing. The grab samples taken at the same time were combined, mixed, and a sample of approximately five grams of usably sized woodchips were randomly selected for moisture determination in the ADL Infrared Moisture Determination Balance Model 4714A. Grab samples of the feedstock taken between the drier and the gasifier were taken in a similar manner, but once an hour. Woodchip samples that could not be immediately analyzed were temporarily placed in "Ziploc"-type plastic bags and analyzed as soon as possible. These data were used to verify the performance of the Dryer and to determine the relationship between moisture in the dried feedstock and system efficiency.

Producer Gas A slipstream of producer gas was taken at CPC after the safety filter and passed through a NOVA gas analyzer after drying to determine the percentages of O_2, CO, CO_2, methane, and H_2 in the dry gas. This data was recorded manually and the gas compositions corrected for an average amount of water vapor before the lower heating values (LHV) were calculated.

Although there is a tar and particulate protocol developed in Europe, it reports all volatile organics, e.g., gasoline components, to be tars and is, therefore, not appropriate for our purposes. The purpose of testing for tars and particulates is to predict the suitability of the producer gas for use in an internal-combustion engine, but the meaningful test is the demonstration of long-term engine operation without tar-related problems, such as sticky intake valves, excessive wear, etc. CPC has confidence in its gasifier design to result in a producer gas having such low tar and particulate values that they do not adversely affect the engines during extended operation. Consequently, determination of tars and particulates in the producer gas was not performed. The extremely low particulate and VOC values measured in the exhaust gases substantiated the effectiveness of the producer-gas filtration to remove particulates and tars.

Bio-Char Grab samples of bio-char made from the Rocky Top wood chips from the two char drums were taken and subjected to testing to determine the plant nutrient, heavy metal content, and the leachable components of interest in EPA's TCLP test protocol. This was done to verify that disposal of the char made from this type of feedstock may be as non-hazardous material.

Net Power and Heat Production The levels of net power and waste heat recovery were sampled once every 26 seconds of operation by the data acquisition system.
After installation and commissioning of the system at Fort Carson, the logged data set was again reviewed for adequacy and was changed as required.

During the Controlled Testing period, the data were analyzed for trends, consistency and reasonableness between the various sensors to identify potentially invalid data and the need for corrective action. Mass and energy balances were made to verify that the data reflects expected results with good closures.

The proper electrical-grid connection and the waste-heat-delivery plumbing to local code requirements required the interaction of CPC engineers, Fort Carson facilities personnel (engineers), and contracted licensed electricians and plumbers. Verification of the proper connection of these utilities was made, as it was critical to the success of this program that it was done properly.

5.6 SAMPLING RESULTS

Char Characterization

Samples of the beetle-killed pine woodchips used as the feedstock and the resulting chars recovered from just after the gasifier and from the filters were submitted to Hazen Research, Inc., to determine their Ultimate, Proximate, Btu values, as well as, their mineral content. As expected, Table 4 shows a very large increase in the ash content of the char, compared to the feedstock. A mass balance on the ash content of the feedstock entering and of the chars leaving suggests that these levels of ash in the recovered chars correspond to a char yield of about 2%. If the feedstock has a lot fines or dirt in it, the char yields will be a bit higher, especially if the gasifier's grate is regularly dumped to control the pressure drop through the gasifier.

The remaining volatiles in the gasifier char reflect the presence of some partially gasified char that had been dumped from the gasifier to correct high pressure drops in the gasifier. The even higher volatile content of the filter char is thought to reflect the tars that had been adsorbed onto the fine filter char during cooling and filtering of the producer gas. The higher sulfur and nitrogen content of the Filter Char is thought to be from their capture from the producer gas, e.g., as H_2S and ammonia, by the adsorption onto the large surface area of the Filter Char.

Table 4. Ultimate, Proximate, and Btu Values

	Woodchips	Gasifier Char	Filter Char
Proximate			
Ash, %	0.87	32.3	44.79
Volatile, %	84.92	7.51	21.59
Fixed C, %	14.21	60.19	33.62
Ultimate			
Carbon, %	51.31	66.57	53.68
Hydrogen, %	6.03	0.23	0.39
Nitrogen	0.14	0.44	0.98
Sulfur, %	0.02	0.04	0.37
Ash, %	0.87	32.30	44.79
Oxygen*, %	41.63	0.42	<0.01
HHV, Btu/lb	8077	9402	7398
LHV, Btu/lb	7518	9382	7362

The results of the char testing showed that both char samples were non-corrosive and non-ignitable. BioMax® System char is not classified as a hazardous waste (see appendix D's letter from the State of Colorado Department of Public Health and Environment confirming this determination). Of the RCRA heavy metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver), only barium was detected in the two chars at 1.6% to 3.9% of the allowable 100 mg barium/L of leachate in the TCLP test. In contrast, some commercial "green" fertilizers have significant amounts of heavy metals in them, e.g., Down to Earth's Acid Mix 4-3-6 All Natural Fertilizer, which has 10 ppm arsenic in it.[13]

The TCLP of the gasifier char showed no volatile organic compounds or semi-volatile compounds in the leachate, whereas, the filter char TCLP released 1.37 mg benzene/L of leachate (exceeding the 0.5 mg benzene/L allowable) and allowable trace amounts of cresols. This level of benzene in the leachate was unexpected and was the first instance of excessive benzene levels in the TCLP test of filter char made from clean woody biomass, although it has been previously reported by us for filter char made from feedstocks containing cardboard and plastics.

CPC demonstrated in a previous DoD project[14] that when the gasifier char and filter char are physically mixed together, benzene is immobilized in the char mixture by the activated-carbon nature of the gasifier char, resulting in acceptably very low levels of benzene in the TCLP leachate. In the future BioMax®100 GEN2 systems, the two chars are collected by the system as one mixed-char by-product that is non-hazardous in nature.

The two chars were also tested for their potential as a fertilizer.Table 5 shows the mineral and nitrogen content of the ash of the two chars and of the chars calculated from the ash composition and the ash content of the beetle-killed pine woodchips. For comparison, a commercial fertilizer such as Vigaro contains 12% N, 5% P_2O_5, and 7% K_2O., The two chars have considerable merit as fertilizers; in particular, the potassium levels in the chars correspond to commercial levels in more dilute fertilizers designated as "non-burning." The calcium, sodium, and potassium content increase the pH of the soil and the ability to retain ammonia fertilizer. These chars can be used for carbon sequestration and for improving the quality of poor soils (i.e., biochar or terra preta).

Table 5. Nitrogen and Mineral Content of BioMax® 100 Chars (8/1/13)

	Gasifier Char Ash	Filter Char Ash	Gasifier Char	Filter Char
SiO2, %	42.26	40.79	13.65	18.27
Al2O3, %	11.07	10.78	3.58	4.83
TiO2, %	0.35	0.36	0.11	0.16
Fe2O3, %	3.41	4.03	1.10	1.81
CaO, %	14.90	20.50	4.81	9.18
MgO, %	3.64	4.74	1.18	2.12
Na2O, %	0.90	0.79	0.29	0.35
K2O, %	8.80	9.02	2.84	4.04
P2O5, %	1.53	2.15	0.49	0.96
SO3, %	0.43	1.25	0.14	0.56
CL, %	0.07	0.42	0.02	0.19
CO2, %	4.07	1.47	1.31	0.66
N, %			0.44	0.98

Combined Heat and Power

Figure 9 shows the steady-state energy flows in the BioMax® 100 measured at 1400 hours on June 5, 2013 at Ft. Carson. The 244 Nm^3/h (1070 SCFM at 0°C and 1 atm.) of producer gas at that time were delivering a calculated 368 kW_{th} to the engines, based on the nominal gas composition and its lower heating value. The energy meter in the heat-transfer fluid (coolant) measured 180 kW_{th}. Of this useful recovered waste heat, 71 kW_{th} was from the Exhaust-Gas Coolant (estimated from the flow rate of producer gas, and temperatures of the engine-exhaust gas entering and leaving the Exhaust-Gas Cooling heat exchanger). Subtracting the exhaust-gas contribution of 71 kW_{th} from the 180 kW_{th} total amount of recovered energy in the CHP Coolant, leaves 109 kW_{th} that was recovered from the engine by the Engine Coolant. This waste heat was recovered, while the generator produced 90 kW_e gross. The parasitic electrical loads averaged 7 kW_e, leaving 83 kW_e for export from the system.

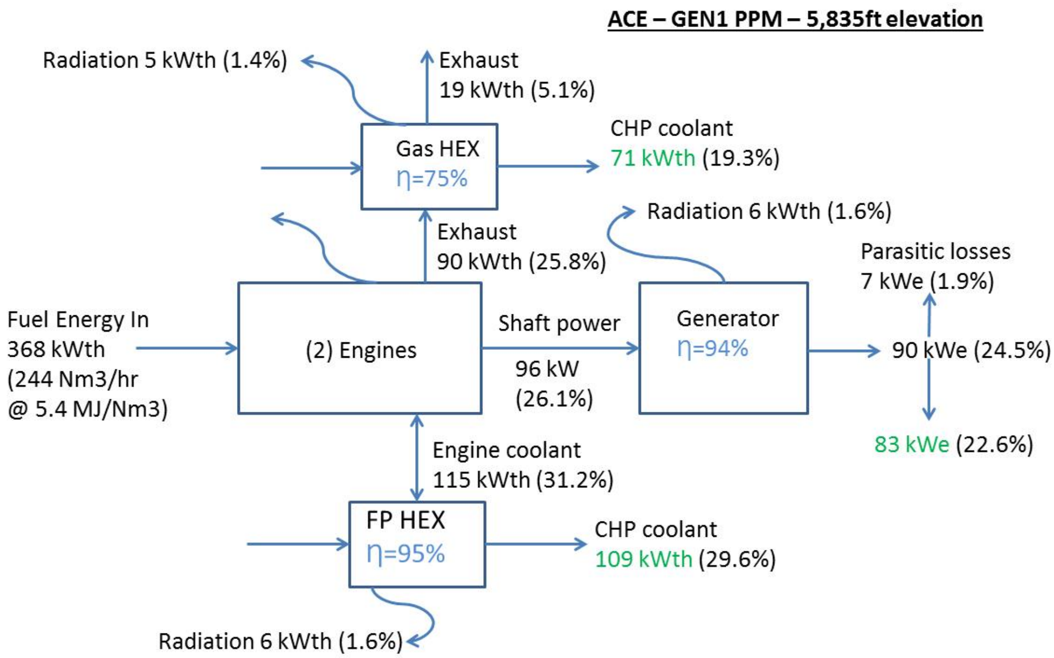


Figure 9. Energy Flow Diagram for the BioMax® 100 CHP system at Fort Carson

By difference, 79 kW_{th} was lost by radiation and convection from the engine and the generator and most of the 7 kW_{th} parasitic power into the interior of the PPM; these heat losses were dissipated by the flow of air generated by the radiator fan. This is about 28% of the energy in the producer gas going into the engine that leaves the PPM as warm air at about 52°C (~126°F). During severely cold weather, this warmed air could be used as pre-heated Producer-Gas cooling air to provide additional energy for drying the feedstock or directly for local space heating (but only with careful attention to monitoring the CO levels in the warm air).

Figure 10 shows the net electrical and thermal power delivered on June 5, 2013 after 0600 hours. The electrical output delivered to the Fort Carson grid is relatively constant with time. The available thermal energy should be as constant, but the actual thermal energy exported depends upon the demand of the building. This causes the exported thermal energy to vary considerably,

but appears to reach a steady state value of 180 kW_{th} at 1400 hours, about 40 minutes after peaking at about 195 kW_{th} at about1320 hours.

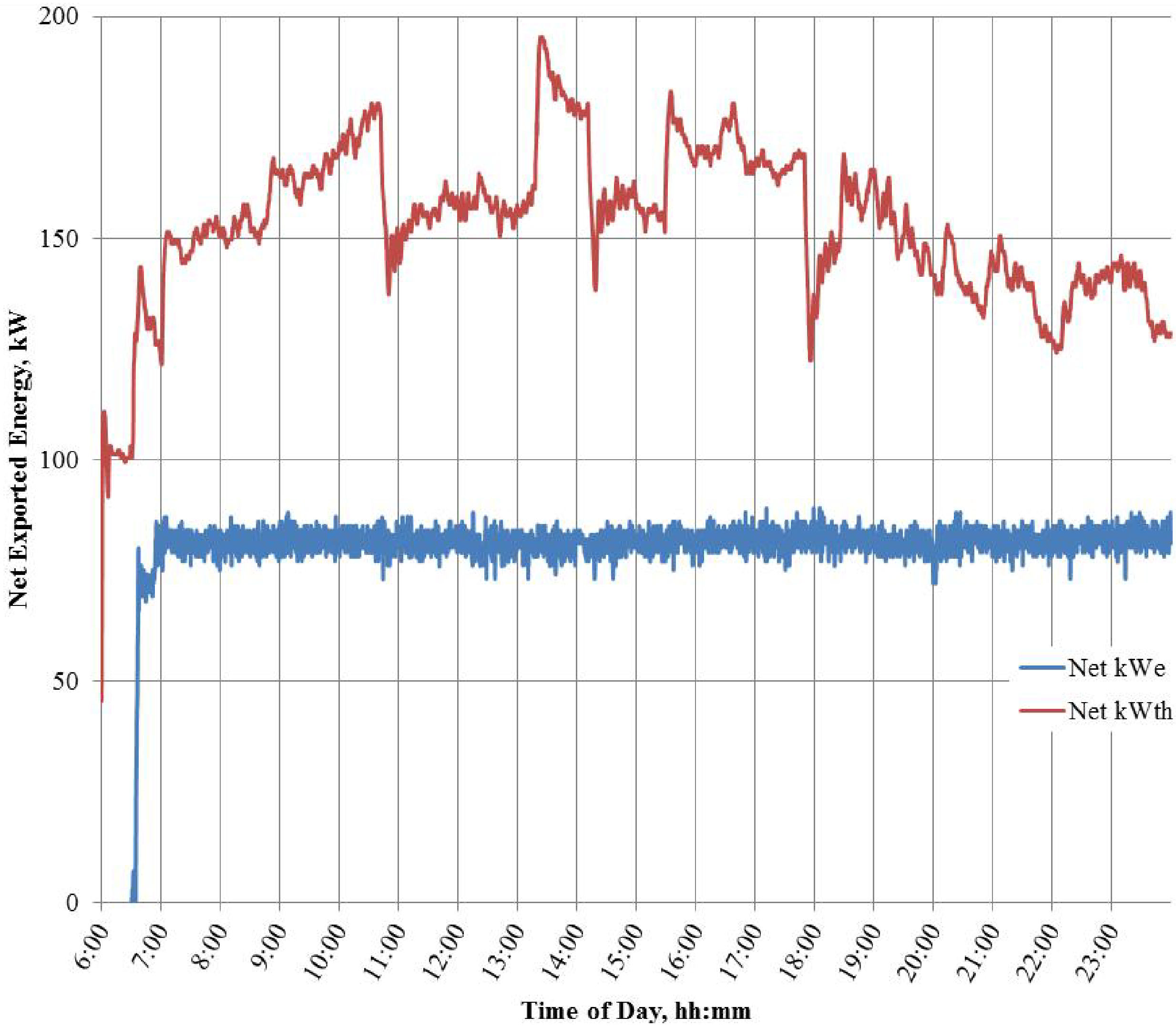


Figure 10. Net Electrical and Thermal Power Delivered to Ft. Carson on 6/5/2013

6.0 PERFORMANCE ASSESSMENT

Prior to shipping the BioMax® 100 system to Fort Carson, we assessed the performance of the system to that point in time and delayed its shipment until we were reasonably confident that we would be able to satisfactorily meet the project's Demonstration goals.

After the Demonstration was completed and we had a significant number of operational hours, we assessed the performance of the system to update the inputs necessary for the technical and Life Cycle Cost evaluations, including feedstock input rates, net electrical and recovered thermal power, availability of the system, recurring operating costs, labor for maintenance, overhead, exhaust emissions, etc.

Carbon Footprint The reduction in carbon footprint is based on the electrical power output and the amount of waste heat recovered. We considered that the carbon dioxide emitted by the BioMax® system is from contemporary carbon dioxide, rather than from fossil sources and not included in these calculations. Thus, the carbon footprint reduction will be equivalent to the carbon footprint of the fossil fuel required to produce the same amount of energy displaced by the BioMax® system.

EPA lists the amount of CO_2 emitted from the generation of electricity as 1,135 lbs CO_2/MWh from natural gas, 1,672 lbs CO_2/MWh from oil, and 2,249 lbs CO_2/MWh from coal.[15] The average value in the U.S. is 1216 lbs CO_2/MWh, although in Colorado it is 1829 lbs CO_2/MWh.[16]

Due to the mechanical problems encountered and the delays in the issuance of operating permits, we were not able to achieve the desired availability in the time allowed, but we were still improving it each month. These GHG values are based on the sustainable delivered electric power level and delivered recovered waste heat level. The only extrapolation was the availability from 74% to 80%.

Using US EPA's Carbon Footprint calculator for electricity generation and space heating with electricity, fuel oil, propane, or natural gas;[17] with an availability of 80% at sea level, a net of 104 kW_e is equivalent to 359 tons of fossil CO_2 per year and the recovered 226 kW_{th} is equivalent to 488 tons of fossil CO_2 from fuel oil per year. The total reduction in CO2 emissions is 847 tons CO_2 / year. These reductions are equivalent to 0.5 tons of CO_2 per MW_eh and 0.3 tons of CO_2 per $MW_{th}h$.

Payback The years to payback was calculated using the values generated in the Field Demonstration for system availability, net electrical output, waste heat recovery, feedstock consumed, cost of consumables, labor, etc. A range of energy and feedstock costs were considered to provide guidance for the prioritization of potential sites for the BioMax® 100 system. Energy value and feedstock costs were determined that yield 7-year simple payback periods, which is discussed in detail in the section 7.0 Cost Assessment. In addition, a NIST Life Cycle Cost Present Value analysis was performed using a more realistic system life of 15 years, which is also discussed in Section 7.

Dryer Performance During the Baseline Characterization of the BioMax® 100 system at CPC, the performance of the dryer was characterized. This required measuring the feedstock fed over a period of time, initial and final moisture contents of the feedstock, the time elapsed, and the local air temperature and relative humidity. The ability of the drier to keep up with the demands of the gasifier was crucial to achieving high system availabilities and high energy outputs. The feedstock moisture was reported on a wet basis (%, lbs water/100 lbs wet biomass). The gasifier works best with feedstocks having between 8 and 18% moisture on a wet basis. The criteria for success was to be able to reduce the moisture content from its initial moisture content down to less than 18% moisture, while sustaining high power outputs.

Figure 11 shows a sampling of the dryer's performance in 2012, which met the demonstration's goals. Further detail on the BioMax® System performance during the Fort Carson demonstration is included in Appendix C to this report. . The feedstock received in 2013 was much drier and did not need drying except on two occasions when the moisture content exceeded 15%. In the relatively dry Colorado climate, the moisture content of the delivered woodchips was rarely above 25%, so the dryer was not tested at its maximum performance capability during the field demonstration period. Some problems were encountered with the feedstock a bit too dry for optimal gasifier operations, which suggests that adding a little water to an overly dry feedstock could be helpful. Excessively high moisture in the feed was only experienced with a small quantity of feedstock in a storage bin that had not been adequately protected from rain (not shown in Figure 10).

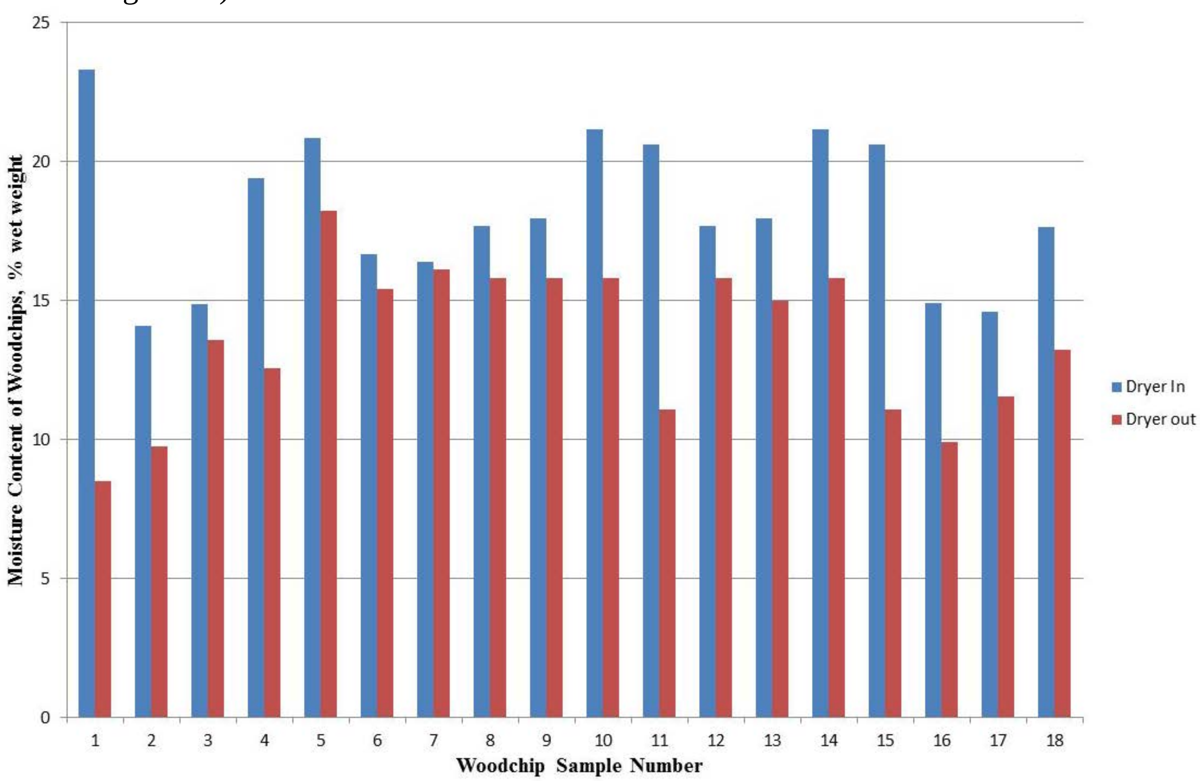


Figure 11. Performance of BioMax® 100 Dryer

Product Gas Quality During the Shakedown and Baseline Characterization of the BioMax® 100 at CPC, we measured the dry producer-gas composition. We used the nominal wet gas

composition to estimate the Lower Heating Value (LHV) of the producer gas at 5.4 MJ/Nm³ (138 BTU/SCF), using the well-established LHV values of the individual gases from the literature. An LHV greater than 115 Btu/SCF (60°F and 4 in. W.C.) is desirable in order to have good combustion characteristics. . The 8.1-L Vortec engines performed well during the entire Field Operation period with this producer gas, during which each engine logged over 1400 hours of operation on producer gas. There were no indications of tar accumulations during field operation, so good quality in the producer gas sent to the engines was demonstrated. The measured particulates and VOC's in the exhaust gases were extremely low due, to the removal of the char fines by the producer-gas filters and the low residual levels of tar vapors in the producer gas, as discussed later in this section under "Emissions Quality." Consequently, we did not quantify the tar and particulate levels in the clean producer gas using CPC's tar and particulate protocol.

Operational Availability The operational availability was that demonstrated at Fort Carson during the Operational Testing, after the lengthy Commissioning and Controlled Testing were completed. Operational Availability is defined as the ratio of the time the BioMax® 100 was functioning during a month to produce power and recovered waste heat at design levels divided by the total time elapsed during that month, expressed as a percentage. When the system was otherwise operationally available, the system availability was not penalized for any downtime due to the following problems outside of the control of CPC:

a) Delayed feedstock shipment due to inclement weather, e.g., closed highways;
b) Inability of the grid to accept the full output of electricity;
c) Inability of the building to accept recovered waste heat;

Because these three problem areas affect the potential income stream, these site specific items will need to be considered and estimated in any detailed economic evaluation of the BioMax® system at a particular site.

Figure 11 shows the percent of the time that the BioMax® 100 system was operating and producing power. Integration of the new PPM into the system and other system integration problems with this prototype gasifier system combined to keep the Monthly Availability of the system quite low until May 2013. The longest continuous run was made starting on June 30 and ending on July 4, 2013 for 104 hours. Although we did not achieve the goal of 80% monthly availability, we were within a few per cent of that goal and getting closer each month.

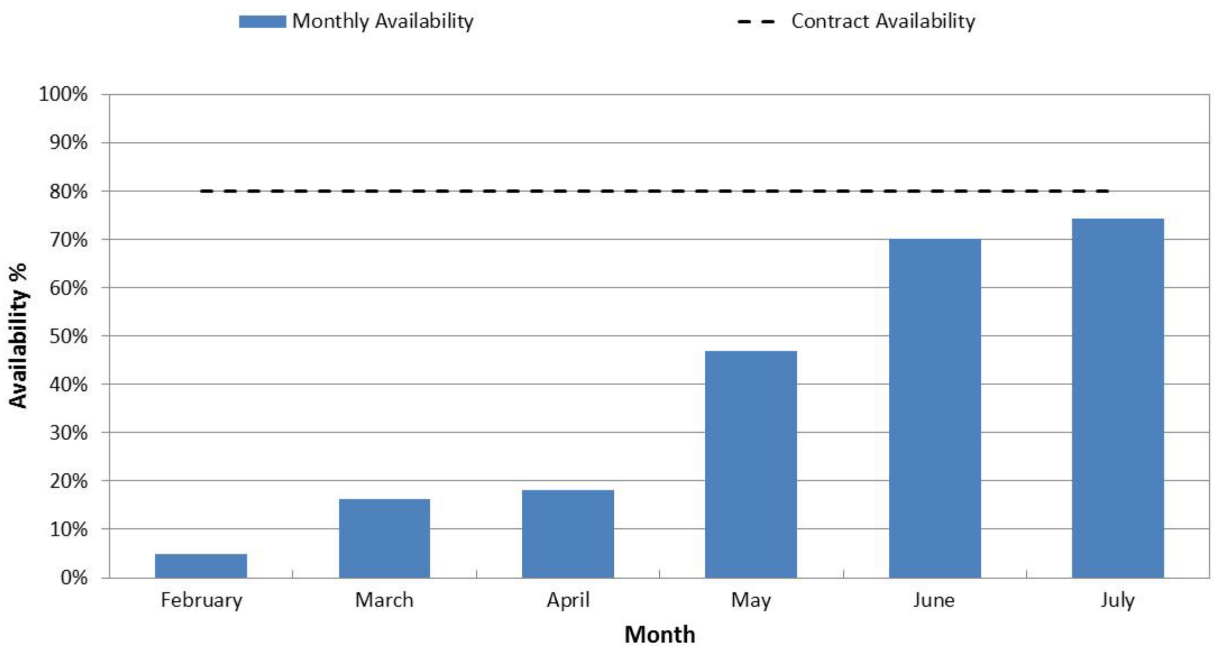


Figure 12. Monthly Availability During 2013 of the BioMax® 100 at Ft. Carson

Figure 13 shows the distribution of the problems that affected the monthly availability after May 23, 2013. Figure 14 shows the total length of time of the shutdowns by their causes. Problems with the gasifier typically resulted in the longest downtime per occurrence, because the gasifier must cool down for most of a day before it can be opened and fixed.

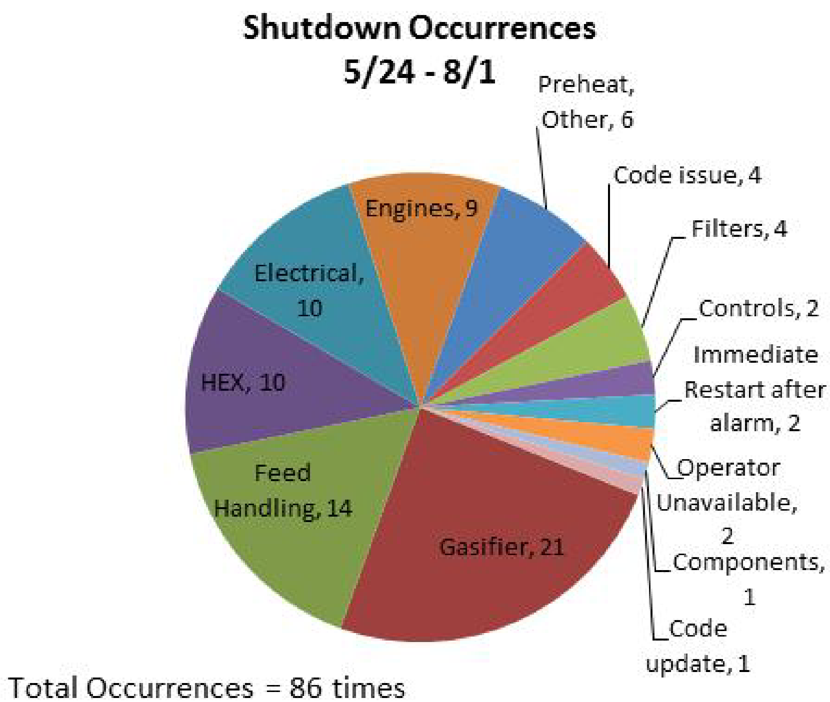


Figure 13. Reason for BioMax® 100 Shutdowns

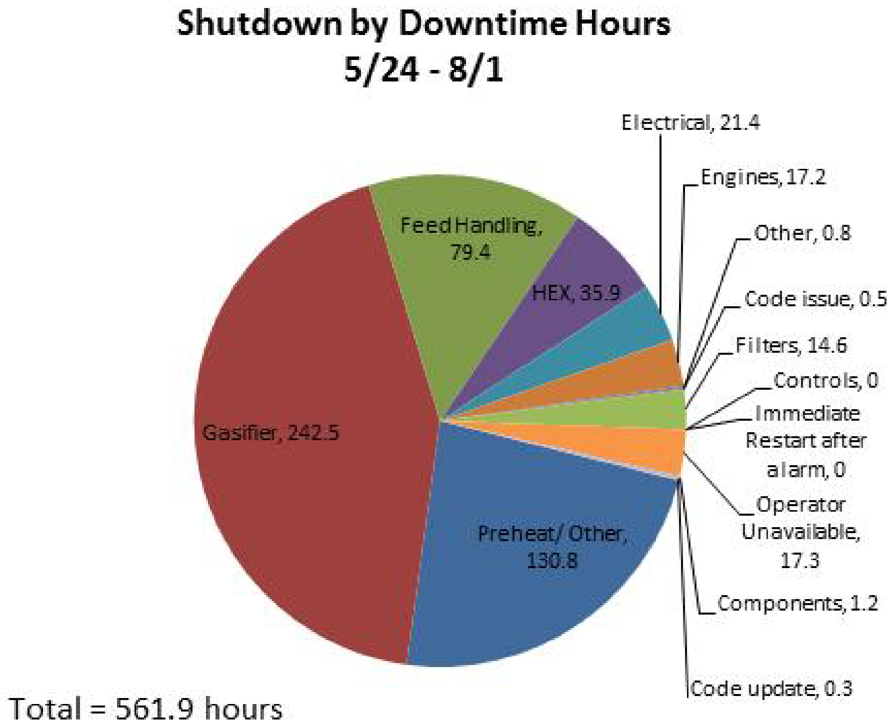


Figure 14. Severity of Shutdowns by Cause

Ease of Use A log of labor required to operate the BioMax® 100, including data review, maintenance, repair, remote system operation, and on-site system operation was maintained with these separate categories, but this did not included travel time from CPC to Fort Carson for on-site activities. However, each trip to Fort Carson from CPC was logged. These data were separately plotted with time to show progress in reducing the amount of operator involvement in the operation of the system. The criterion for success was to be able to operate the system on a basis of 24 hours per day and 7 days per week with a total of one operator after the first month of commissioning and controlled testing. We were able to run 24 hours per day (unattended after the day shifts) and achieved up to 104 hours (4.6 days) of continuous operation.

Reliability of Technology The reliability of this first prototype BioMax® 100 system steadily improved during the Field Demonstration, but did not reach the goals of MTBF of less than 21 days. However, the average downtime required to repair or maintain the BioMax® 100 was only an elapsed time of 6.5 hours , easily meeting the goal of less than an average of 48 hours per occurrence.

Figure 15 shows the dates, causes, and length of duration of the system shutdowns after May 23, 2013. It is seen that the Engines and the Feed Handling were problems initially, but were resolved by late June. The gasifier was initially not a problem, but was thereafter a common issue causing a system shut down for maintenance primarily, as expected. The severity of the gasifier-caused shutdown is pronounced due to the time required to cool the gasifier, before it can be maintained.

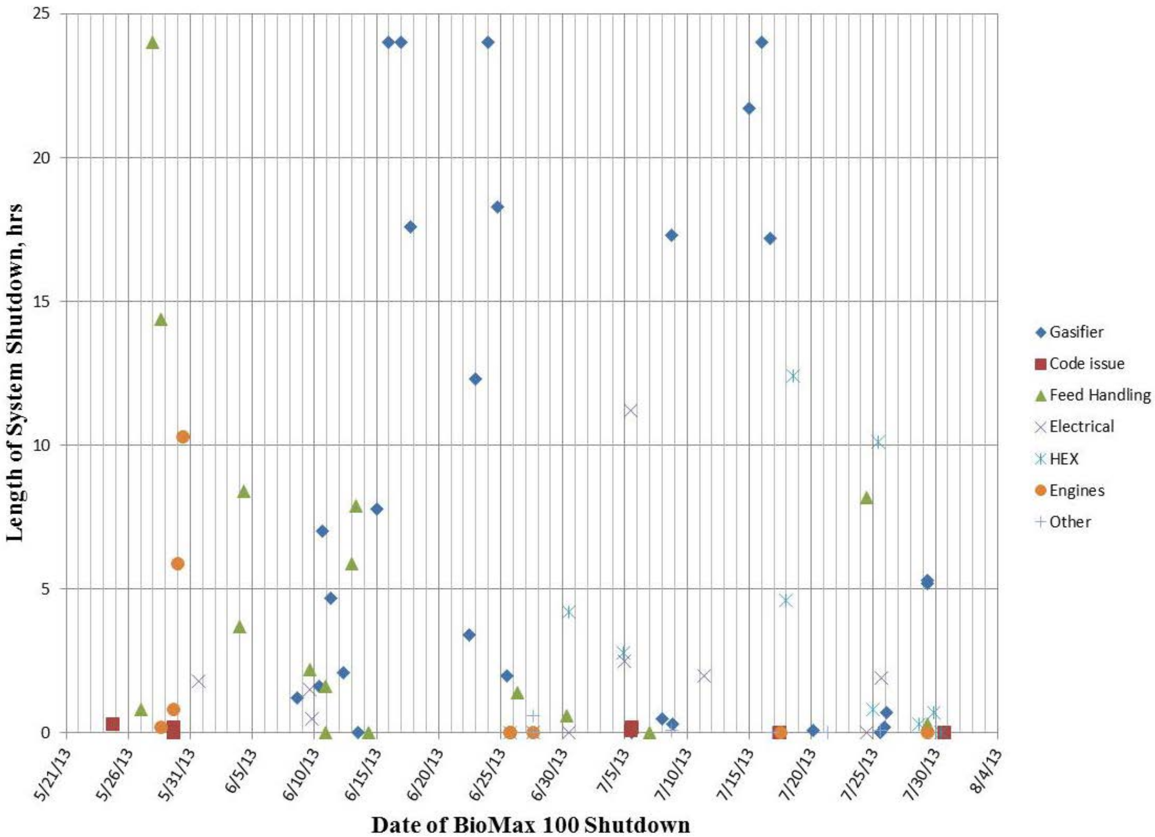


Figure 15. Date, Cause, and Severity of System Shutdowns

Gross Power and Heat Production The net electrical power exported from the BioMax® 100 to the grid was recorded with a power meter and reported as kW_eh. The net recovered waste heat delivered was calculated by the commercial Onicon Btu meter from the measured flow rate of the heat-transport fluid and its temperature as it entered and left the PGM. The extent of heat losses in delivering the recovered waste heat from the BioMax® 100 to the client's building will be site specific and were not included in the recovered energy values. The criteria for success was to consistently deliver in excess of 100 kW_e and 150 kW_{th} (500,000 Btu/hr) and meet the operational availability goals.

The BioMax®100 system was able to deliver 83 kW_e at the high elevation of Fort Carson of 5,830 feet above sea level. This net electrical power output is in excess of the contractual goal of 75 kW_e at an unspecified altitude by a comfortable 11%. A "sister" BioMax® 100 system in CA is at 131 feet elevation and has produced a net of 104kW_e for export to the grid, exceeding the CPC goal of 100 kW_e by 4%. This lower performance at high elevation (80% of that at sea level) is well predicted by the ratio of the local atmospheric pressures (~11.9 psia at Ft. Carson divided by ~14.7 psia at 131 ft elevation or ~0.81). This factor was divided into the waste heat recovered at Fort Carson to extrapolate the expected waste heat recovery, when operating at sea level.

Even at the reduced electrical power generated at Ft. Carson's high elevation, 180 kW_{th} of waste heat were recovered from the engines' exhaust gases and coolant, exceeding the contractual goal

of 150 kW_{th} by 20%. This value of recovered heat does **not** include the heat remaining in the flue gases as they left the stack nor the radiant heat lost from the engine block and exhaust manifold that was exhausted to the atmosphere as warm air. At sea level, the recovered waste heat is extrapolated by the atmospheric pressure ratio to increase further to 240 kW_{th}, based on the increased gross electrical power output at the lower elevation.

Emissions Quality It is desired to have very low emissions of CO, NO_x, and hydrocarbons. Because the siting of the BioMax® 100 could be in locations with very stringent emission requirements, it is paramount to the ease of obtaining environmental permitting that the engine exhaust emissions be very low. To accurately measure these low levels of pollutants requires rigorously maintained specialized equipment and well trained technicians, which are best supplied by a specialized environmental testing contractor.

The particulates in the exhaust gases from the 8.1-L vortec engines were measured on August 7, 2012, while burning only producer gas at CPC and found to average only 0.000313 grain/dscf. This low level of particulates is a result of the removal of the char fines from the producer gas by the filters and the low level of residual tar vapors that could react to form particulates in the engine.

The US EPA regulations of Jan. 18, 2008 for New Stationary Emission Sources, found in 40 CFR Part 60 JJJJ, require emissions be measured only after the system has reached a steady-state condition. They limit gasoline-fueled internal combustion engines having a displacement over 200 cc and producing less than 19 hp to emissions specified in 40 CFR part 1054 to be less than 8 g (NOx+HC)/hp-hr and 610 g CO/hp-hr.

Producer gas is not mentioned in 40 CFR Part 60 JJJJ, but the allowable emissions when fueling a spark-ignited engine with natural gas are: 1 g NOx / hp-hr; 2.0 g CO / hp-hr; and 0.7g VOC / hp-hr.

During the Baseline Testing at CPC period, we retained the services of an environmental testing contractor to measure the concentration of the pollutants and the flow rate of the exhaust gases from the 8.1-L Vortex engines, using the test protocols specified in 40 CFR Part 60 for spark-ignited engines. The gaseous emissions from the 8.1-L GM Vortec engines were considerably below the upper limits allowed by 40 CFR Part 60 "Standards of Performance for stationary spark Ignition Internal Combustion Engines," when fueled with either gasoline or with producer gas. No further exhaust-emission testing was required to obtain the Colorado operating permit.

Although the test protocols required by the California Air Resources Board (CARB) are a little different from those required by the Federal regulation, it is of interest to compare the upper limits allowed for distributed power generation with waste gases, which include digester gas, landfill gas, and oil-field waste gases. Our producer gases are produced from materials that would otherwise be disposed as wastes, analogous to the gases produced by biological methods from waste materials in landfills.

After December 31, 2007 the upper limit specified by CARB for emissions from engine/gensets burning waste gases were:

a) 0.5 lb NO_x / MW-hr;
b) 6.0 lb CO / MW-hr;
c) 1.0 lb VOC / MW-hr

Note that if the system's overall system thermal efficiency exceeds 60% and recovers waste heat for useful purposes, then that exported recovered heat is added to the net electrical power to increase the MW-hr denominator in the measured emission calculation. With a demonstrated "near sea-level" performance of a electrical power of 104 kW_e added to the projected 240 kW_{th} for a total of 344 kW, the emissions measured while fueling with producer gas on 8/7/12 using the Federal test protocols are:

a) 0.49 lb NO_x / MW-hr
b) 0.20 lb CO / MW-hr
c) 0.013 lb VOC / MW-hr

This assumes that the exhaust emissions would not increase at the higher exhaust throughputs that exist at the higher engine output demonstrated at the lower elevation. These calculations suggest that the BioMax® 100 would be in compliance with the CARB regulations effective after December 31, 2007 for waste gas. However, as of January 1, 2013, the current CARB Regulations for Distributed Power no longer have the waste-gas category and they are now excessively restrictive, with only our VOC emissions now in compliance. However, these CARB regulations are only in effect in California in the rare case, where there is no local air quality management district.

Environmental regulations of the local air-pollution-control districts in California may require testing with different test protocols for air emissions and have different allowable emission values. The local air quality management districts in California can be more or less strict than the CARB regulation for distributed power generation. It was out of the scope of this project to investigate and satisfy every local regulation. However, a large number of states adopt the federal environmental requirements as their own, with California being an exception.

Bio-Char Quality and Usage Samples of char recovered from the filter and from just after the gasifier were tested to verify that they are non-hazardous materials for disposal and could be used as a soil amendment. This included testing for heavy metals (RCRA) and for toxic materials that could easily leach out of the char in a landfill (TCLP), as well as, for ten elements known to be plant nutrients such as nitrogen, potassium, phosphorus, etc. The criterion for success was that the bio-char retain its current non-hazardous designation. The mixed chars made from walnuts in a similar, but smaller BioMax® 50 at Winters, CA, have been more intensively studied and found to be non-hazardous in the State of California.

Although the Filter Char had benzene levels that exceeded the very low TCLP limits, it has been previously demonstrated[14] that when the two chars are mixed together that the gasifier char acts as an activated carbon to immobilize benzene released by the Filter Char. It is concluded that the mixed chars will be non-hazardous for disposal purposes, if there is no local market for them.

However, the chars have considerable economic value in them, both as fertilizer and as soil amendment. Due to the powdery nature of the chars, their application to the land may need to be as a water-slurry injected below ground level to minimize particle emissions (PM) in the air, as practiced by a walnut farm in Winters, CA.

7.0 COST ASSESSMENT

7.1 COST MODEL

In order to maintain the factory-built, modularity, and mobility of the BioMax® systems, CPC does not now contemplate further scale up of the BioMax® from its current gasifier size, although small incremental power increases may be attained as the system matures and bottlenecks are eliminated. Consequently, where more feedstock is available and more power is desired, CPC will propose using multiple BioMax® 100 systems operating in parallel. This approach provides a superior ability to load follow for maximum efficiencies. Thus, the cost model chosen does not evaluate the beneficial effect of scaling up the relatively small scale of the BioMax® 100 system.

Table 6 shows Cost Elements and necessary data needed for the development of the cost model. Explanations of each cost element follow the table. The cost assessment is based on making several modifications to the BioMax® 100 design that were tested in the last several months of this demonstration.

Table 6. Cost Model for the BioMax® 100 System at Sea Level

Cost Element	Details	
Capital Cost	including shipping, training, & commissioning	$1,121,000
Consumables	Estimates of the cost of charcoal, filters, engine oil, etc.	$18,326/yr
Facility Operational and Maintenance Costs	• Operational labor • Frequency of required maintenance • Maintenance labor • Total Labor cost	Daily, Weekly, Yearly, 2-yearly $25,480/yr
Hardware lifetime	Estimate based on component degradation during demonstration	15 years
Feedstock Cost	Dry basis	$40/ton
Feedstock Rate	Dry basis	2 lb/kW$_e$h gross
Feedstock cost/yr	Using the values from this table	$38,894
Electricity Produced	At about sea level (100% useful to client)	100 kW$_e$
Recovered Waste Heat	At about sea level, extrapolated from Ft. Carson data (100% useful to client)	222 kW$_{th}$
System Availability		80%

7.2 COST DRIVERS

Hardware Capital Costs An accurate Bill of Materials and costs were maintained during the build of the BioMax® 100 system used in this demonstration. However, these costs were based on buying many of the items one at time or in low volume and we did not have the advantage of lower costs possible when buying in larger quantities, as an original equipment manufacturer would.

Assembly Costs The labor required to assemble this first prototype unit was tracked by our accounting department. We expect the succeeding assemblies to go much faster and predictably with lower resulting costs. We have now assembled four other BioMax® 100 systems for other clients and one new BioMax® 100 GEN2 prototype.

Installation Costs The labor required to first re-assemble the modules and the controlled testing at Fort Carson were recorded. The labor to re-assemble succeeding systems was then estimated, taking into account an experience factor. The installation costs are included in the total capital cost.

Consumables The BioMax® 100 uses very few consumables, but they are significant in cost, as Table 6 shows. This cost includes standard consumables such as oil, grease, filters, gaskets and seals as well as BioMax® System specific items such as char/ash disposal bags, charcoal (startup feedstock), gasifier air injection fingers, replacement blowers, and bi-annual engine overhauls. However, after the gasifier's grate is serviced, the gasifier is filled with commercial charcoal prior to starting the next period of operation. The oil and oil filter in the generator's engine must be changed at the engine manufacturer's recommended intervals. A log and cost of these consumables was maintained during the field demonstration and used to project the life-cycle costs.

Facility Operational Costs A detailed timesheet was used to break down the time charged to various facets of operating the BioMax® 100 in the field, e.g., data review, remote operating, on-site operating, scheduled maintenance and repair, breakdown maintenance and repair, number of site trips, etc. These costs were used to project facility operational costs for the Life-Cycle evaluations.

Maintenance Using the maintenance logs from the Operational Testing phase, the labor and parts to keep the system running were used to project these costs for the economic evaluations. In addition, the summary of the maintenance required was used to identify subsystems in need of improvement. Based on good experience at another BioMax® system operating site, it was assumed that the engines would need to be rebuilt only every other year.

Hardware Lifetime At the end of the Operational Testing, the system was examined for signs of wear, which could be used to estimate the expected lifetime of the equipment and alter the expected operating expenses during long pay-back periods.

Other than the bulge in the gasifier (discussed in Section 8), there was nothing observed that indicated incipient failure or excessive wear. It is assumed that the excessive-temperature-control issue will be resolved and that the hardware will have a 15-year life, with engine rebuilds every two years.

Operating Training Due to the high degree of system automation, it is expected that operating training requirements will be fairly low and not be a major part of the operating costs. However, this cost was estimated for the Life-Cycle analysis and is included in the total capital costs.

Energy Cost Avoidance The system was credited with the energy costs avoided by virtue of the electrical and thermal energy delivered by the system, assuming that the facility can beneficially utilize all or an assumed fraction of the delivered thermal energy. For example, in evaluating the potential for the use of thermal energy, some candidate facilities under consideration in the model may only have a short period per year of thermal energy usage. It will be assumed that all electrical and thermal energy generated will be consumed by the host site. More complex situations can be estimated from these data.

7.3 COST ANALYSIS AND COMPARISON

Simple Payback Perspectives Figure 16 shows the relationship between the value of the electricity produced and the value of the recovered thermal energy required for a 7-year simple payback, with the assumptions that:

a) the recovered thermal power is linearly proportional to the gross electrical power output;
b) all recovered net thermal and net electrical energy is used by the client to offset conventional fossil energy sources;
c) higher gross electrical outputs require proportionately more feedstock;
d) $40/dry ton of biomass feedstock;
e) 2 lbs/hr dry feedstock/gross $kW_{e;}$
f) $1,121,000 capital investment including installation and commissioning costs;
g) $25,480 / year Operating and Maintenance costs;
h) $18,326 / year Operating Materials costs, including charcoal, motor oil, etc.;
i) 111 kW_e gross electrical output;
j) 100 kW_e net electrical output;
k) 222 kW_{th} available in hot water;80% efficient fossil fuel boilers/air heaters for comparison to fossil fuel costs; and
l) 80% BioMax® system availability.

The important economic parameter is the local value of the usable electrical and thermal energy, each of which is the product of:

a) the availability of the BioMax® system;
b) the client's energy load profile;
c) the value per unit of the energy displaced, and
d) the energy output levels.

Because the power output of the engines is degraded at the lower atmospheric pressure present at higher elevations, two curves are shown in Figure 16 that are based on the performance of the BioMax® 100 at:

a) Ft. Carson at 5830 ft. elevation with 90 kW_e gross (83 kW_e net) and 180 kW_{th} net; and
b) Sea level, with performance corrected by the ratio of the atmospheric pressure at sea level divided by that at Fort Carson, to result in 111 kW_e gross (100 kW_e net) and 222 kW_{th} net. (This correction was validated when a "sister" BioMax® 100 system in CA at 131 ft. elevation fed with walnut shells produced 113 kW_e gross (104 kW_e net) and could produce an extrapolated 226 kW_{th} net).

In Figure 16, any combination of thermal and electrical values that are above the curve of interest will result in a simple pay-back period of less than 7 years. Some sites will have only seasonal use for the recovered waste heat, which has a negative impact on the economics. To use Figure 16, if the thermal energy can only be used 40% of the time, then the correct equivalent value of the cost of thermal energy to use in Figure 15 is 40% of the displaced heating fuel's local energy cost per MMBtu.

The value of the recovered waste heat depends upon the fossil fuel it displaces and upon the local distribution and delivery costs to the client. Typical recent average costs in the U.S. during 2013 of recovered heat from various fossil fuels[18] are shown across the top of Figure 16, when burned in a boiler having an assumed efficiency of 80%.

For example, the average contiguous-U.S. price of recovered heat from No. 2 Fuel Oil at \$4.11/gallon was \$41.62 MMBtu, assuming a specific gravity of 0.80, an 80% efficient fossil-fuel boiler, a heating value of 18,500 Btu/lb (0.123 MM Btu/gal of fuel). .

The effect of operating at the lower power level at the higher elevation is to increase the cost of electricity by about \$0.061/kW_eh. The effect of a cheaper feedstock costing \$10/dry ton less is to shift the curves downward by about \$0.011/kW_eh. The effect of increasing the net electrical power by 10 kWe is to shift the curves downward by \$0.028/kW_eh. The effect of reducing the installed capital cost by \$100,000 is to shift the curves downward by about \$0.030/kW_eh. If these reductions in cost were all met for a \$0.07/kWh reduction in electrical cost, then the Massachusetts Industrial case near sea level would have still have over a 7-year simple payback period.

The low electrical and heating costs are shown for Ft. Carson, where a BioMax® 100 system would not meet the assumed 7-year payback. Industrial-sized users of natural gas and electricity in Massachusetts have higher energy costs than at Fort Carson in Colorado, but the payback period would still be longer than seven years. However, in an island environment such as Hawaii (where all fossil fuels are imported a long distance), the high cost of both electricity and natural gas to industrial users combine for a payback period of less than 7 years.

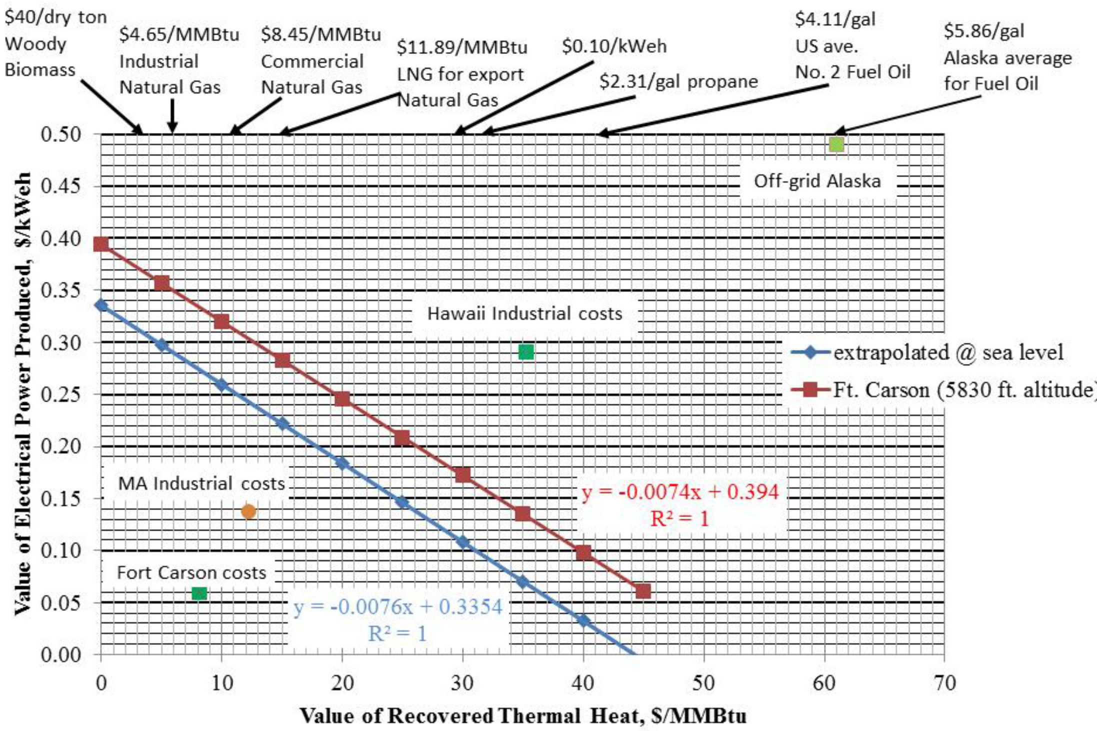


Figure 16. Coinciding Energy Costs Required for a 7-year Simple Payback

Figure 17 shows the results for several different simple payback periods, using the sea-level performance of the BioMax® 100, and the same cost parameters as in Figure 16. The Hawaiian Industrial example would have a simple payback period of a little under three years.

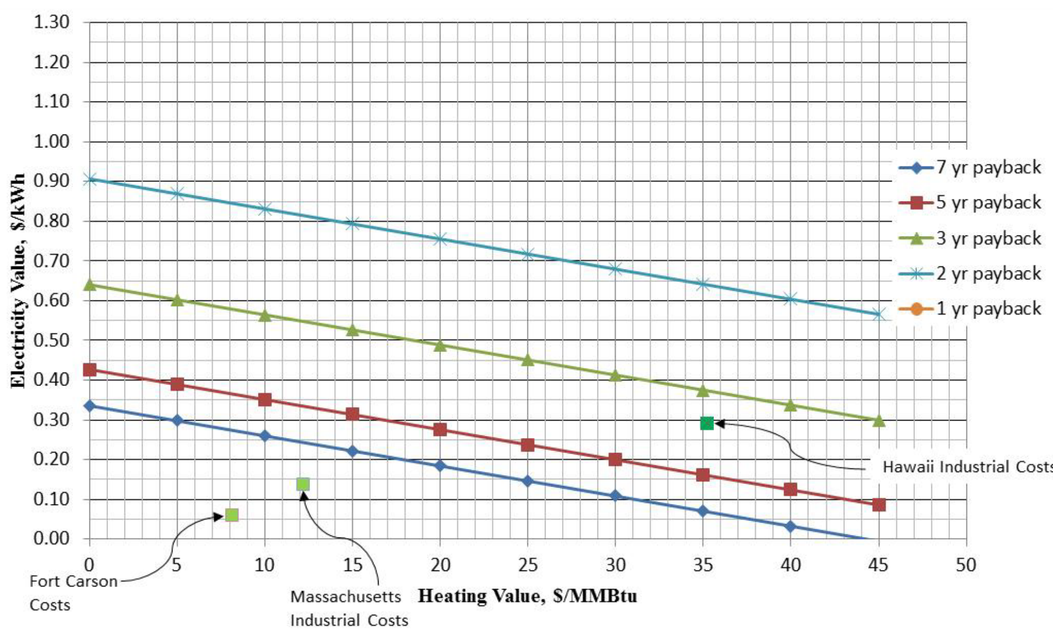


Figure 17. Effect of Energy Costs on Various Simple Payback Periods at Sea Level

Figure 18 shows a pie chart of the projected annual variable costs of labor, materials, and feedstock. Feedstock costs of \$40/dry ton (a feedstock cost of \$0.04/kW_eh at 2 lbs dry feedstock/kW_e) were assumed, as was an 80% availability of the BioMax® 100 system.

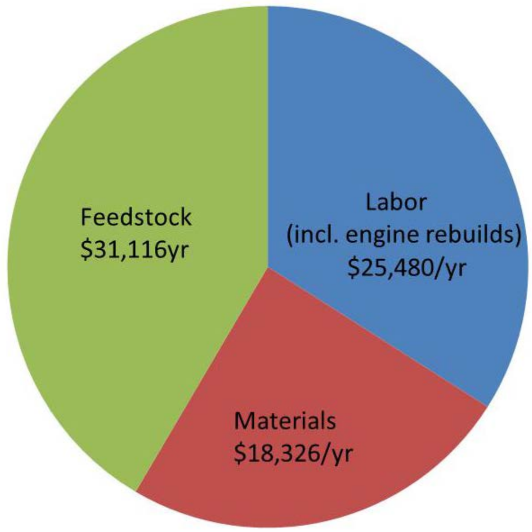


Figure 18. Projected Variable Cost Distribution with the BioMax® 100

Life-Cycle Cost CPC performed a final Life Cycle Cost evaluation using the experimental results of the 6-month field demonstration and the system's projected cost and performance for the BioMax®100 at sea level. Table 7 summarizes the Life Cycle Cost (MILCON Energy) analysis made by the NIST computer program based on the NIST Handbook 135 for Building Life Cycle Costing. A site in Massachusetts was selected because of the high local energy costs there. Values were used for the industrial costs of electricity of \$0.1378/kWeh and recovered heat from natural gas of \$12.175/MMBtu (in an 80% efficient boiler), which are listed for industrial users in Massachusetts in 2013 according to the U.S. Energy Information Administration. A 15-year life of the BioMax® 100 was assumed, with engine rebuilds every two years and no salvage value for the system. An availability of 80% was assumed, as was the ability to utilize all of the electricity produced and all of the recovered waste heat from the engines' coolant and exhaust gases. The MILCON Analysis, Energy Project option was selected from the NIST BLCC 5.3-13 software, which used a 3% discount rate. It was assumed that the client already had a boiler in place and that the BioMax® 100 would be supplementing the existing boiler's output and displacing the fossil fuel used by the existing boiler, as well as, the BioMax® 100 supplementing the existing use of electricity from the local electrical grid.

A possible alternative to a BioMax®100 system would be military engine/gensets powered by diesel engines, i.e., two 60-kW military Tactical Quiet Generators (TQG's). The cost of each TQG is \$48,613 [19] each, or \$97,226 for the two TQG's required to generate 100 kW_e. These TQG's do not recover any waste heat. The two TQG's would consume a total of 8.14 gal diesel fuel per hour of operation at the combined net load of 100 kW_e (based on measurements previously made at CPC with a 60-kW TQG). The operating manual requires an oil change every 300 hours of operation that uses 20 quarts of motor oil per engine. An average cost of \$3.00 per quart of motor oil was assumed. JP-8 was assumed to have the same average price as

No. 2 Fuel Oil at $4.11 per gallon. This results in a variable cost of $0.335/kWh, just for the JP-8. An average availability of 80% was assumed, as were operational and maintenance costs of $2.94/hr[20].

The NIST software was designed for comparing modifications to buildings, so it appeared to only allow the consumption of electricity and of fossil fuels for heating, not the generation of electricity and heated water. To remedy this dilemma, the present values of the investment costs and operating costs (operating, maintenance, repair, and feedstock) from the NIST LCC were subtracted from the present values of the electricity generated and the heat recovered by the BioMax® 100.

The results of these extra calculations are shown in Table 7, where the operation of two 60 kW TQG's results in the negative present value of -$3,308,559, whereas, the operation of a BioMax® 100 results in a positive present value of +$323,904 (with Combined Heat and Power). Even without recovery of waste heat, the BioMax® 100 system still has a much higher present value than the operation of the TQG's. Thus, the BioMax® 100 present value is worth $3,632,463 more than operating the two 60 kW TQG's over a 15-year period, when the electrical and heating (JP-8) energy costs are those found in Massachusetts.

Table 7. NIST BLCC 5.3-13: Summary LCC (Massachusetts fuel costs)

Present Values	**Two 60 kW TQG's**	**Without CHP BioMax® 100**	**With CHP BioMax®100**
Initial Cost	- $97,226	-$1,113,000	-$1,121,000
Fuel Cost	-$3,982,527	-$469,816	-$531,404
Routine OM&R Cost	- $699,953	-$661,421	-$661,421
Electricity Exported Value	+$1,471,147	+$1,484,603	+ $1,484,603
Recovered Heat Value	0	0	+ $1,153,126
Total	**-$3,308,559**	**-$759,634**	**+$323,904**

With the assumptions used in this study, it is concluded that where long term generation of combined electrical and heating power are required, that the deployment of a BioMax® 100 rather than two 60 kW TQG's would result in a significant cost savings over a 15-year period. In fact, the production of only electricity (without CHP) with the BioMax® 100 fed biomass has a better present value (less negative) than the alternative case of operating two 60-kW TQG's fueled with JP-8.

Transition Plan from Product Development to Production

CPC used this information to develop a transition plan. Testing continues on Alpha BioMax® 100 Systems similar to one utilized on this project. Lessons learned from these systems will be worked into the Beta Gen2 BioMax® Systems with the goals of improving reliability and output, while reducing cost.

Other changes made to achieve economies of scale include the relocation of CPC's operation to a new facility in the Denver Metro area, near Centennial Airport at 14800 Grasslands Drive, Englewood, CO 80112. The new 50,400 square foot facility houses both administrative and

engineering offices as well as an expanded warehouse and manufacturing area. The new facility was designed to produce up to 72 BioMax® 100 GEN2 units per year.

Sales representatives are working to development markets for BioMax® System. Efforts have been concentrated in the West Coast, Northeast, and Hawaii, where energy costs are higher. Options being explored with potential clients include direct sales, leasing, and owning-and-operating.

Assisting in the sales efforts are government incentives. Federal income tax investment tax credits (ITCs) are available for CHP systems. Thirty percent (30%) credits are available for CHP systems as long as construction begins prior to December 31, 2013. Subsequent to that date, a ten percent (10%) credit is available for systems placed in service before December 31, 2016. These ITCs are critical in making the economics for early system installations work for both CPC and its customers.

At this time, CPC does not envision scaling up the BioMax® 100 to a larger size, although it is anticipated that minor system changes will increase the magnitude of the exported electric and thermal power. This will keep the systems small enough to be factory built and transported to the site in rugged ISO containers that then serve as equipment shelters. For those sites that could supply the required feedstock and consume the power generated, CPC will propose using multiple BioMax® 100 systems operating in parallel. This paralleling of systems will greatly increase the availability of the overall system, with planned maintenance occurring on only one of the BioMax®100 systems at a time.

8.0 IMPLEMENTATION ISSUES

Environmental Regulations

Military installations are required to meet local rules and regulations for air, water, and soil pollution. Early discussions with personnel representing the local air quality district are highly recommended to avoid program delays due to a slow permitting process. The BioMax® system represents a potentially new and different source of pollution to most of the air permitting personnel. Unfortunately in the past, there have been environmental problems with some biomass gasification systems by others that were not well engineered.

This requires an effort to educate both the military and local civilian environmental groups involved on this new technology of CPC that produces:

a) no liquid wastes for disposal;
b) a minimum of solid char as a non-hazardous byproduct for disposal or a soil amendment (Note: the feedstock must not be an uncontrolled waste to avoid possible contamination with hazardous materials); and
c) a very clean producer gas used to fuel a spark-ignited internal combustion engine resulting in low exhaust-gas emissions.

The engine-exhaust stack releases the odor-less engine-exhaust gases high above the ground level, much higher than that from a TQG, to minimize personnel exposure to oxygen-depleted gases having trace amounts of toxic compounds in them, e.g., CO, SO_2, etc.

Many military installations are under pressure to reduce their total emission levels, rather than being encouraged to increase them. A distributed electrical-power generation system providing a constant base load will add to the total emission levels, whereas emissions from an emergency power system would be of a short duration and probably not be counted. Consequently, the evolving history of successful installations with low emissions at other sites will be a strong selling point.

Noise levels need to be kept to a minimum, with a goal of less than the 70 dB at 7 m allowed for a TQG. The fans and air blowers appear to the source of the majority of the noise from the BioMax® 100, which is designed to contain this noise and minimize noise levels.

Gasifier Shell Integrity

Upon removal of the insulation from the BioMax® 100 gasifier, evidence of high-temperature metal creep was found in the SS304 gasifier shell. Figure 19 shows that this creep resulted in a bulging of the gasifier shell, between the first and second char-air injection nozzle planes. The char-air finger holders appear to have reinforced the gasifier shell. Normal operating temperatures are typically higher below the second char-air injection level than above it, suggesting that the conditions of high temperature that caused this creep were not part of the normal operating regimes.

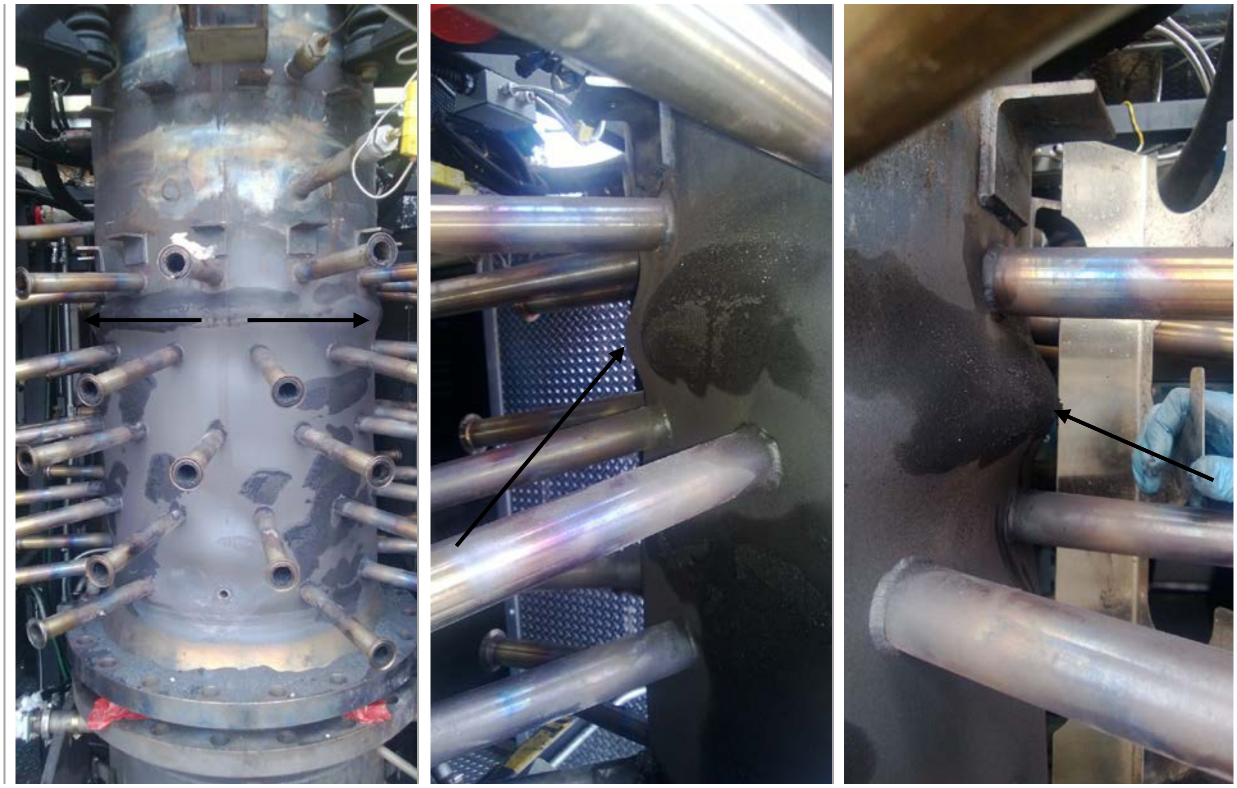


Figure 19. Bulged Gasifier after Demonstration Testing at Fort Carson

The moisture, liberated by the terminal drying process of the moist feedstock produced during pyrolysis and combustion in the flaming pyrolysis zone of the gasifier, reacts with the char to absorb energy by making hydrogen and carbon monoxide. This reaction occurs progressively faster at higher temperatures and serves to moderate the char temperatures above about 800°C. If the gasifier has consumed all of the fresh feed, there is only char remaining in the gasifier and no significant source of water, which results in extremely high temperatures.

It is hypothesized that this gasifier-wall deformation occurred during one or more abnormally high temperature excursions that could have been caused when:

a) the control system failed to recognize the need to add more fresh feedstock, or
b) a "controlled shutdown" of the gasifier failed to shut down the system before excessively high temperatures occurred in the upper levels of the char bed.

Because the gasifier normally operates at 1 to 2 psig negative pressure, it would appear that the deformation, that bulges outwardly, might have occurred after the gasifier had been shut down and the valves all were closed, because the gasifier experiences a momentary small pressure increase at that time. However, the burst disks in the system keep the system pressure below 7 psig.

In the event of a failure of the shell wall during operation, air will be pulled into the gasifier through the opening, making the local char zone even hotter. This will lead to excessively high temperatures in the char bed being reported to the control code, which will shut the system down. The gasifier shell is wrapped with flexible fiber insulation and a protective cover of stainless

steel sheet metal, which serve also to provide some personnel protection, although personnel are normally not present in the Gas Production Module during operation.

The outward bulging is now hypothesized to be due primarily to the local thermal expansion of the gasifier shell in the localized over-heated horizontal strata of the gasifier; bulging inwardly would not relieve these thermal-expansion induced stresses. Corrections to the control code are being made to ensure operation of the gasifier at lower temperatures, similar to how a “sister” BioMax® 100 system is operated, which does not have this problem of rapid metal creeping.

Grid-Tie Issues

The most efficient mode of operation of the BioMax® 100 is to provide a base load, rather than one that provides a variable peak load. Operation with low electrical loads will decrease the potential income from electricity and recovered waste heat, as well as, tend to lead to char deposits in the producer-gas heat exchanger and more frequent maintenance. Consequently, it is imperative to connect to the local grid, so that the commercial grid or local engine/gensets fueled with fossil fuels provide peak power demands above the base load.

Because commercial grid providers are faced with similar efficiency effects, they will tend to resist accepting electrical power exported beyond the military installation boundaries. This can require the installation to guarantee to the commercial electricity provider that no power will be exported off the base, which is usually not a problem due to the relative size of the BioMax® 100 system compared to the total electrical usage of the installation.

For smaller bases that cannot guarantee that no power will be exported beyond their boundary, there may need to be studies by the power company to determine what upgrades to the local power infrastructure may be required to distribute power from the BioMax®, as well as, liability insurance. The costs of these studies, new equipment, and insurance would be borne by the client.

To connect to a grid requires that the BioMax® is generating power that is at the correct voltage and frequency. In addition, the frequency of the electricity generated has to be in phase with the grid power. An example of this equipment is the Perkins EASYGEN, which samples the grid power and forces the BioMax® generators to the same frequency and the correct phase angle. The BioMax®100 system includes all of the electrical equipment necessary to synchronize with and connect to an existing power grid and will shut down the system if the grid power is interrupted. This last feature is necessary to protect the linemen who may be sent out to repair a faulty grid. To convert the BioMax® 100 to also be automatically a back-up system, would require the addition of about $1,700 worth of electrical equipment, which is currently being added to the new version of the BioMax® 100 systems. This extra equipment is exemplified by the Beckwith Electrical system that disconnects the grid in the event of a grid failure, which reduces the power generated by the BioMax® 100 to only that consumed locally.

Local power companies that provide the grid may have additional requirements, such as a guarantee that absolutely no power will be exported to the grid from a generator. If the client’s electrical usage is sufficiently large that the output from the BioMax® system is relatively small,

there probably will be no net export of power to the grid. However, meeting a strict no-export guarantee will require additional electrical equipment, which is commercially available and costing between about $4,000 and $15,000 for the BioMax® 100, depending upon the requirements imposed by the grid provider.

A permit to connect to a grid is normally required by the power company. The length of time required, the difficulty, and the cost of attaining this permit varies considerably within the U.S. power industry, reflecting each of the individual power company's requirements and attitudes toward accepting distributed power generation.

Feedstock Issues

Although this test program only tested softwood chips made from Beetle-killed pine, a large number of other feedstocks, including hardwood chips,have been successfully gasified in BioMax® systems over the years, but especially walnut shells. The composition of the resulting producer gas from the various feedstocks is relatively constant, reflecting the close approach to thermodynamic equilibrium in the gasifier. However, there have been some problematic feedstocks.

It is known that the feedstock needs to have a low tendency to form bridges in the feed hopper and in the gasifier, which eliminates feedstocks that resemble sticks and favors shapes that tend to have low angles of repose (spherical or cubical shapes). Exceptionally wet feedstock may not be dried sufficiently in the BioMax® dryer to permit good gasification. Feedstocks with unusual mineral contents may change the gasification characteristics, due to catalytic effects of the minerals. Feedstocks with high contents of hydrocarbons can result in high levels of benzene or tars adsorbed onto the filter char, which requires special handling or extra maintenance. Hardwood chips are stronger than softwood chips, which can jam screw conveyors, so conveyor belts are preferred for transferring hardwood chips (and other feedstocks). Feedstocks with particle sizes smaller than ¼ inch tend to have excessively high resistance to gas flow and high differential pressures; they also may require a different size of holes in the gasifier's grate.

It is recommended that CPC be consulted concerning the suitability of a particular feedstock for gasification in the BioMax® system. It may be necessary to complete gasification tests at CPC to determine the feedstock's suitability.

Permitting Issues

Although the BioMax® 100 systems are being proven to be very clean systems with unusually low emissions, public perception of burning wood involves a lot smoke and carbon monoxide emissions. In addition, there have been previous attempts by others using inferior gasification and control technologies, which have resulted in adverse environmental impacts. Consequently, to avoid lengthy delays in permitting, it is imperative that the local air quality management authorities be contacted early in the deployment schedule and provided with a solid technical background in the BioMax® gasification and control technology.

Governmental and Utility Incentives

At the present time, there are financial incentives available from a variety of governmental and utilities to utilize more alternative energy sources. The BioMax® systems will qualify for many of these incentive programs, although they are all subject to change. A tax expert should be able to assist the client to determine if any such financial incentives are available for a proposed site to reduce the capital cost of the BioMax® 100.

End-Users' Concerns, Reservations and Decision-Making Factors

The concerns of the military installation have included:

a) environmental impacts (addressed at the beginning of section 8.0 of this report);
b) visual appearance of the BioMax® 100 modules;
c) visual impact of normal operations and of process upsets (e.g., smoke);
d) odors with normal operating and upset conditions;
e) orderly appearance with proper feedstock and char containment; and
f) noise.

The visual appearance of the BioMax® 100 system is a small grouping of 20' ISO shipping containers and a semi-truck trailer delivering the feedstock, which can be all painted to the military's specifications to blend in with other military equipment.

Due to the overall combustion efficiency of the two-step process of CPC gasification and engine fuel/air control, there are no apparent odors from the BioMax® 100 system during normal operation, except for the dryer's exhausted wet air that has a faint woodchip odor. There can be a small amount of smoke briefly emitted from the closed-top of the gasifier during an emergency shutdown of the system. This smoke odor is similar to that of a distant campfire and is easily tolerated by most personnel after dilution with air during its brief and rare emission.
For the base commander to be enthusiastic about accepting the BioMax® 100, it would be advantageous for there to be:

a) incentives in place for the command to reduce dependency on off-base power and fuel supplies;
b) potentially unreliable sources of electricity and fossil fuels;
c) relatively high variable electrical and fossil costs;
d) an openness to alternative energy sources;
e) an abundant supply of feedstock nearby or within the installation's boundaries that is being harvested or culled;
f) evidence presented of the low polluting nature of the BioMax® 100 compared to diesel engine/gensets;
g) an increased availability level for the BioMax® 100 system;
h) low manpower requirements for operation; and
i) demonstrated operation by military or contracted personnel.

Items a) through e) are site specific issues that vary from one installation to another. CPC has consistently developed the BioMax® systems to have low pollution characteristics and low

manpower requirements featuring a fully automatic system that provides reliable operation without an operator being physically present.

Procurement Issues

The BioMax® 100 is in the early stages of commercialization. The prototype BioMax® 100 used in this demonstration was the first of its kind and was considerably modified during the early part of the demonstration. To date, three other BioMax® 100's have been built based on the final version of this first system, which are now in the field.

CPC has just recently moved to a new location that will facilitate producing the BioMax® 100 at a rate of up to 72 systems per year. CPC is now in the process of establishing efficient assembly methods with ongoing quality assurance, which will have the desired effect of producing reliable systems on a regular basis at lower cost.

However, the BioMax® 100 was inherently more expensive than desired.   A second generation ("GEN2") version of the BioMax® 100 has been designed and is currently being fabricated and assembled that significantly lowers the parts count and cost.   It is expected that the first GEN2 unit will need a lengthy commissioning period, before reliable 24/7 operation is attained. The first prototype of the upgraded BioMax® 100 GEN2 is in early evaluation testing.

In summary, the BioMax® 100 is currently available in relatively small numbers. The first prototype of a less expensive BioMax® 100 GEN2 is being tested, which will significantly lower the capital investment in the near future and have a higher CHP energy output.

Appendices
to
Modular Biopower System Providing Combined Heat and Power for DoD Installations

ESTCP: EW-200940

APPENDIX A. POINTS OF CONTACT

POINT OF CONTACT Name	Organization Name Address	Phone FAX E-mail	Role in Project
Jim Galvin, PhD	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3600	(571) 372-6397 James.j.galvin.civ@mail.mil	Sponsor/Contracting Officer Representative; Program Manager – Energy & Water, US Dept of Defense
Vince Guthrie	Fort Carson, Directorate of Public Works Fort Carson, CO	(719) 526-2927 Vincent.e.guthrie2.civ@mail.mil	Site host Utility Programs Manager
James Diebold, P.E.	Community Power Corporation 18400 Grasslands Dr. Englewood, CO 80112	(303) 577-2965 (303) 933-1497 jdiebold@gocpc.com	Engineer Assisting the CPC Lead Person (King Browne); Co-Author
Kevin Buelke	Community Power Corporation 18400 Grasslands Dr. Englewood, CO 80112	(303) 577-2979 (303) 933-1497 kbuelke@alutiiq.com	CPC Lead Person (Replacing Mr. Browne)

APPENDIX B. SANDIA NATIONAL LABORATORIES REPORT

Final Report

CPC Demonstration Project

Site Selection and Evaluation

Sandia National Laboratories

June 10, 2010

Sandia Authors:
Scott Paap, Todd West, Blake Simmons

1.0 Introduction

Many Department of Defense (DoD) facilities are thought to have access to significant resources of underutilized or non-utilized biomass resources that could be used to reduce the dependency of those facilities on fossil fuels for the combined production of electrical power and recovery of waste energy for building heating (CHP).

The goal of the contract between the U.S. Army and Community Power Corporation (CPC), Lockheed Martin (Owego), and Sandia is to demonstrate the use of biomass in a relatively small modular BioMax® 75 system to produce 75 kW of electricity and to recover 300,000 Btu/hr of waste heat for space heating in a DoD building over a period of one year. This system will consume up to about 600 tons of biomass per year (on a dry basis). Lockheed-Martin in Owego, NY (LM) will be assessing the potential of this technology for DoD applications. Sandia National Laboratory in Livermore will provide biomass-resource information to aid in the demonstration site selection and also in the assessment of the potential of this technology for widespread deployment within DoD.

2.0 Decision Factors and Ranking Systems

The criteria for site selection include:

1) Reliable sources of up to 600 tons of woodchips over the 12-month demonstration period, either from the facility's grounds or from within an economical distance for reliable delivery from multiple local sources. Ideally, this would be a site having surplus woody biomass that is already being chipped and disposed in an expensive manner, e.g., by landfilling;

> a. Note that the woodchip sources for the demonstration do not need to be sustainable, i.e., the woodchips could come from forest thinning or a non-sustainable forest cleanup, following a devastating insect infestation, wind storm, or fire.

2) A facility that has a strong dedication to reducing fossil-fuel use, preferably located where grid electricity and heating fuels are both expensive, thus providing strong economic incentive to the facility to support this demonstration that will deliver heat and electrical power;

3) A location having a long cold season, requiring significant building heating to make the capture of waste heat more valuable and advantageous to the host site;

> a. However, severe arctic-winter temperatures are not necessary to demonstrate the building-heating aspect of the demonstration.
>
> b. Sites where water heating is required, and that can take advantage of CHP in the form of hot water, will also be considered in lieu of space heating.

4) A facility that is easily accessible by both Lockheed-Martin (Owego) and CPC personnel for their support roles in the field demonstration;

> a. A potential demonstration site within either New York or Colorado, for easier access by either CPC or LM would have special merit in the site selection criteria.

5) A location that is not having severe air quality issues that would make air permitting overly restrictive or onerous; and

6) A location near a population center from which it is reasonable to expect to be able to hire a suitable technician to train to operate the BioMax® system.

3.0 Results

3.1 Proposed Sites and Justification:

1. Barksdale Air Force Base (Bossier City, LA)
    - Base Commander: Col. Steven L. Basham
    - Base phone number: (318) 456-1110
    - Base area, in acres: 22,000
    - Electricity price: 5.94 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 306,554
    - Biomass availability onsite: >1000
    - Website: http://www.barksdale.af.mil/
    - Key features: Barksdale was one of the 2009 Federal Energy and Water Management Award winners from DOE. The base has had a long-standing focus on improving sustainability for base operations and would appear to have the appropriate motivation The facility covers more than 22,000 acres and has a significant amount of woody biomass (>300,000 tons) available for the project.

2. Fort Bragg (Fort Bragg, NC)

- Base Commander: Lieutenant General Frank Helmick
- Base phone number: (910) 396-0011
- Base area, in acres: 8000
- Electricity price: 5.64 cetns/kWh
- Propane price: N/A
- Heating oil price: N/A
- Biomass availability, 25 mi radius (tons): 201,691
- Biomass availability onsite: >1000
- Website: http://www.bragg.army.mil/default.htm
- Participant DOD Forestry Program
- Key features: Ft. Bragg initiated an energy efficiency initiative and is at the forefront of the DoD's efforts to minimize cost at bases associated with electricity consumption. As such, they are a very strong candidate for the deployment and evaluation of the CPC unit. The base spends an average of $40M/year on electricity. The installation has access to a significant supply of woody biomass that is well in excess of the needs to power the CPC demonstration unit.

3. Fort Eustis (Newport News, VA)

- Base Commander: Brig Gen Brian R. Layer
- Base phone number: (757) 878-4920
- Base area, in acres: 7900
- Electricity price: 6.87 cents/kWh
- Propane price: 149.1 cents/gallon
- Heating oil price: 214 cents/gallon
- Biomass availability, 25 mi radius (tons): 145,781
- Biomass availability onsite: >1000
- Website: http://www.eustis.army.mil/
- Key features: Fort Eustis is a 9000 acre training facility that houses the US Army Transportation Corps. The leadership of the facility is committed to energy efficiency and green procurements. In June of 2009, the facility broke ground on the new TRADOC facility, with an emphasis on LEEDS ratings and decreased energy consumption. The facility has access to more than 140,000 tons of woody biomass.

4. Fort Polk (Leesville, LA)

- Base Commander: Brig Gen James C. Yarbrough
- Base phone number: (337) 531-2911
- Base area, in acres: 198,000
- Electricity price: 5.94 cents/kWh
- Propane price: N/A
- Heating oil price: N/A
- Biomass availability, 25 mi radius (tons): 282,008
- Biomass availability onsite: >1000

- Website: http://www.jrtc-polk.army.mil/
- Participant DOD Forestry Program
- Key features: Home of the Joint Readiness Training Center, this massive installation of greater than 190,000 acres has access to a significant amount of woody biomass (>280,000 tons) that would be available to power the demonstration unit. The base has been engaged with several energy efficiency efforts, including a large geothermal pump project (initiated in the 90's) in collaboration with Oak Ridge National Laboratory. In addition, the base is committed to increased readiness and response to the threat posed by hurricanes, and the CPC unit may be a key mobile resource to supplying power to regions impacted by these events.

5. Fort Shafter (Honolulu, HI)
    - Base Commander: Lieutenant General Benjamin R. Mixon
    - Base phone number: (808) 449-7110
    - Base area, in acres: 1100
    - Electricity price: 26.13 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 1500
    - Biomass availability onsite: TBD
    - Website: http://www.army.mil/info/organization/unitsandcommands/commandstructure/usarpac/
    - Key features: Home of USARPAC, this facility is part of the Army's Western Power Grid Peak Demand and Energy Reduction Program (http://army-energy.hqda.pentagon.mil/programs/grid.asp) and is committed to reducing energy consumption. The location in Hawaii is near to the LMC installation evaluating thermochemical conversion technologies. The primary feedstock that would be locally available is eucalyptus and other woody biomass types, and the site has access to enough material to power the CPC demonstration unit, although cost considerations need to be taken into account and further analysis may be warranted as the biomass availability in Hawaii is not well documented.

6. Marine Corp Base Quantico (Quantico, VA)
    - Base Commander: Colonel Daniel J. Choike
    - Base phone number: (703) 784-2741
    - Base area, in acres: 59,000
    - Electricity price: 6.87 cents/kWh
    - Propane price: 149.1 cents/gallon
    - Heating oil price: 214 cents/gallon
    - Biomass availability, 25 mi radius (tons): 113,067
    - Biomass availability onsite: >1000
    - Website: http://www.quantico.usmc.mil/

- Key features: With a base area of greater than 59,000 acres and access to more than 32,000 tons of logging residue, this facility is a strong candidate given its seasonal temperature cycles and proximity to a large metropolitan area with easy access for CPC personnel. The Marines also have an aggressive energy reduction and cost savings campaign in place (see Facilities Energy & Water Management Program Campaign Plan), and the Marine Corp Base at Quantico is a prime target for realizing energy savings given its size and location.

7. Moody Air Force Base (Valdosta, GA)
    - Base Commander: Colonel Gary W. Henderson
    - Base phone number: (229) 257-3501
    - Base area, in acres: 11,000
    - Electricity price: 7.69 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 155,908
    - Biomass availability onsite: >1000
    - Website: http://www.moody.af.mil/
    - Key features: Moody has a stated mandate of reducing energy use by 15% this year and has established a Moody Energy Team to identify new opportunities and execute facility modifications to meet this targeted reduction. A newly opened dorm facility is employing geothermal and improved lighting efficiency as an example of their commitment to energy reduction. These proactive approaches and philosophies, coupled with the large base size (11,000 acres) and woody biomass availability (>91,000 tons of logging residue), make this a strong candidate for system deployment.

8. Naval Air Station Whiting Field (Milton, FL)
    - Base Commander: Captain Pete Hall
    - Base phone number: (623) 796-7197
    - Base area, in acres: 3700
    - Electricity price: 6.57 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 107,219
    - Biomass availability onsite: TBD
    - Website: http://www.cnic.navy.mil/whitingfield/index.htm
    - Participant DOD Forestry Program
    - Key features: NAS Whiting Field has an aggressive and ambitious position towards energy efficiency and sustainability. Although the primary focus of this initiative to date has been around increased water efficiency, the command structure has indicated that they are committed to decreasing electricity consumption and increasing energy efficiency for the entire installation. The

facility has access to a significant amount of biomass (>100,000 tons of total forestry residues) and is located on a facility with easy access for CPC personnel.

9. Naval Station Everett (Everett, WA)
    - Base Commander: Captain Thomas Mascolo
    - Base phone number: (425) 304-3202
    - Base area, in acres: 220
    - Electricity price: 4.42 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 214,253
    - Biomass availability onsite: TBD
    - Website: http://www.cnic.navy.mil/everett/index.htm
    - Key features: Located in the greater Seattle area, this facility has access to some of the most abundant woody biomass (>200,000 tons) in the United States within a major metropolitan area. The base has a commitment to increasing energy efficiency onsite and has several programs underway in improving building energy efficiency and reducing electricity consumption. The successful deployment and testing of the CPC unit at this location may offer very strategic opportunities in terms of longer-term contracts for more units given the regional availability and abundance of the desired feedstock material.

10. United States Air Force Academy (Colorado Springs, CO)
    - Base Commander: Lt. Gen. Michael C. Gould
    - Base phone number: (719) 333-1110
    - Base area, in acres: 18,000
    - Electricity price: 5.97 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 1734
    - Biomass availability onsite: TBD
    - Website: http://www.usafa.af.mil/
    - Key features: As one of the nation's premier military academies, this facility has both the size and regional availability of woody biomass that makes it an attractive candidate for deployment and testing of the CPC unit. In addition, the presence of academic researchers and a broader engagement around renewable energy and energy efficiency create a welcoming climate for this trial evaluation. The academy is part of the Air Force's broader energy reduction campaign.

11. United States Naval Academy Annapolis (Annapolis, MD)
    - Base Commander: Vice Admiral Jeffrey L. Fowler
    - Base phone number: (410) 293-1583
    - Base area, in acres: 1200
    - Electricity price: 9.47 cents/kWh
    - Propane price: N/A

- Heating oil price: 219.9 cents/gallon
- Biomass availability, 25 mi radius (tons): 14074
- Biomass availability onsite: TBD
- Website: http://www.usna.edu///homepage.php
- Participant DOD Forestry Program
- Key features: As one of the nation's premier military academies, this facility has both the size and regional availability of woody biomass that makes it an attractive candidate for deployment and testing of the CPC unit. It also has a winter cycle and consumes heating oil at a relatively high price index. The presence of academic researchers and a broader engagement around renewable energy and energy efficiency create a welcoming climate for this trial evaluation. In fact, the Naval Academy offers several courses on renewable energy and one on biofuels. The academy is part of the Navy's broader energy reduction campaign.

12. Naval Air Station Oceana
    - Base Commander: Captain Markham K. Rich
    - Base phone number: (757) 433-3131
    - Base area, in acres: 5800
    - Electricity price: 9.75 cents/kWh
    - Propane price: 144.5
    - Heating oil price: 217.4 cents/gallon
    - Biomass availability, 25 mi radius (tons): 9425
    - Biomass availability onsite: TBD
    - Website: http://www.cnic.navy.mil/oceana/index.htm
    - Participant DOD Forestry Program
    - Key features: U.S. Naval Air Station (NAS) Oceana is very committed to renewable energy and recently had a groundbreaking ceremony Nov. 19 for a $44 million base-wide Energy Savings Performance Contract (ESPC, Phase II). These upgrades will replace aging infrastructure with more efficient and sustainable systems, improve comfort for base personnel, meet federal energy reduction goals, and enable the bases ability to continue to operate effectively in the face of shrinking budgets

13. Ft Leonard Wood (MO)
    - Base Commander: Major General David E. Quantock
    - Base phone number: (573) 596-0131 x3-6116
    - Base area, in acres: 62000
    - Electricity price: 4.7 cents/kWh
    - Propane price: 144.8 cents/gallon
    - Heating oil price: 218.4 cents/gallon
    - Biomass availability, 25 mi radius (tons): 41244
    - Biomass availability onsite: TBD
    - Website: http://www.wood.army.mil/wood_cms/index.shtml
    - Participant DOD Forestry Program

- Key features: Ft. Leonard Wood houses the United States Army Maneuver Support Center of Excellence. It is charged with building strong soldiers, leaders, families, and forces in a Joint, Interagency, Intergovernmental, and Multinational environment. They are known to partner extensively with industry and academia to support operational missions. This site appears to have a strong intersection between biomass availability and natural gas/heating oil prices. It is also part of the DOD forestry program.

14. Naval Surface Warfare Center Carderock (Bethesda, MD)
    - Base Commander: Captain Chris D. Meyer
    - Base phone number: (215) 897-7596
    - Base area, in acres: 210
    - Electricity price: 6.87 cents/kWh
    - Propane price: 149.1 cents/gallon
    - Heating oil price: 214 cents/gallon
    - Biomass availability, 25 mi radius (tons): 33967
    - Biomass availability onsite: TBD
    - Website: http://www.navsea.navy.mil/nswc/carderock/default.aspx
    - Participant DOD Forestry Program
    - Key features: Carderock is the Navy's center of excellence for ships and ship systems. The mission and workload of the Carderock Division requires extensive R&D facilities. The facilityWork is performed across the life cycle of naval vehicles and includes the full breadth of technologies associated with surface ships; submarines; boats and craft; unmanned vehicles, ranging from small models in laboratories to large models; and operational ships in the ocean environment. As such, the staff and leadership at the facility is extremely comfortable with executing R&D programs and should be open to the challenges associated with the CPC program. The facility is also part of the DOD forestry program.

15. Grissom Air Reserve Base (Kokoma, IN)
    - Base Commander: Colonel William T. Cahoon
    - Base phone number: (765) 688-3348
    - Base area, in acres: 1400
    - Electricity price: 5.58 cents/kWh
    - Propane price: 143.8 cents/gallon
    - Heating oil price: 216.6 cents/gallon
    - Biomass availability, 25 mi radius (tons): 9443
    - Biomass availability onsite: TBD
    - Website: http://www.grissom.afrc.af.mil/
    - Key features: The facility is a joint use civil airport/military base with the Grissom Aeroplex that provides general aviation and charter service. As such, it is very easy to access and should be amenable to the installation of the CPC unit. It also has an extended winter coupled with biomass availability that satisfies several of the CPC criteria.

16. Naval Station Great Lakes (Great Lakes, IL)
    - Base Commander: Captain John Malfitano
    - Base phone number: (847) 688-1583
    - Base area, in acres: 2400
    - Electricity price: 7.47 cents/kWh
    - Propane price: 149 cents/gallon
    - Heating oil price: 217.2 cents/gallon
    - Biomass availability, 25 mi radius (tons): 4644
    - Biomass availability onsite: TBD
    - Website: http://www.usna.edu///homepage.php
    - Key features: Naval Station Great Lakes hosts the Navy's only Recruit Training Command. Each year approximately 37,000 men and women complete the requirements to become Navy Sailors. There is a long winter season here and the combination of relatively high prices for heating oil, electricity, and propane. The base is of sufficient size to theoretically support a large amount of woody biomass. There should be no access problems for CPC staff. The facility also has an established policy around promoting energy efficiency and renewable energy to decrease operational expenses.

17. Fort Drum (Fort Drum, NY)
    - Base Commander: Colonel Ken Riddle
    - Base phone number: (315) 772-5461
    - Base area, in acres: 109000
    - Electricity price: 9.34 cents/kWh
    - Propane price: 147.2 cents/gallon
    - Heating oil price: 225.2 cents/gallon
    - Biomass availability, 25 mi radius (tons): 27449
    - Biomass availability onsite: TBD
    - Website: http://www.drum.army.mil/sites/local/

- Key features: Fort Drum is a large facility with a high amount of biomass available on an annual basis. There is also a long winter season, and there is a strong combination of relatively high prices for electricity, heating oil, and propane. In addition, Fort Drum has a commitment to sustainability in its strategic plan: "The Fort Drum Installation Strategic Plan is one that evolved with a focus on the Army's 'Triple Bottom Line', (Mission, Community, Environment). The principles of sustainability emphasize a long-term, strategic perspective and underscore the fact that Army installations are not independent islands, but a part of a larger regional environmental, economic, and social system." All of these factors make it a strong candidate for CPC selection.

18. Scott Air Force Base (Belleville, IL)
    - Base Commander: Colonel Gary Goldstone
    - Base phone number: (618) 256-1110
    - Base area, in acres: 2900
    - Electricity price: 7.47 cents/kWh
    - Propane price: 149 cents/gallon
    - Heating oil price: 217.2 cents/gallon
    - Biomass availability, 25 mi radius (tons): 10506
    - Biomass availability onsite: TBD
    - Website: http://www.scott.af.mil/
    - Key features: Mission
    - The primary mission of Scott Air Force Base is global mobility. The base commands and controls all logistics of United States military in air, over land and across the sea. The facility jointly houses the MidAmerica St. Louis Airport, and as such accessibility to the site should not pose a problem. The site has an extended winter season with reasonable prices for electricity, propane, and heating oil.

19. Dover Air Force Base (Dover, DE)
    - Base Commander: Colonel Manson Morris
    - Base phone number: (302) 677-3000
    - Base area, in acres: 3300
    - Electricity price: 9.43 cents/kWh
    - Propane price: 145 cents/gallon
    - Heating oil price: 226.4 cents/gallon
    - Biomass availability, 25 mi radius (tons): 9007
    - Biomass availability onsite: TBD
    - Website: http://www.dover.af.mil/
    - Key features: Dover AFB is home to the 436th Airlift Wing, known as the "Eagle Wing" and the 512th Airlift Wing, our Air Force Reserve associate--referred to as the "Liberty Wing." Dover AFB operates the largest and busiest air freight terminal in the Department of Defense and is also home to the Air Mobility Command Museum, and welcomes thousands of visitors each year to the facility.

Therefore site access should not pose a problem. There is a significant amount of biomass available locally, and the pricing for electricity, heating oil, and propane make it an attractive site for this CPC project.

20. Joint Base McGuire-Dix-Lakehurst (formerly Naval Air Engineering Station Lakehurst, NJ)

- Base Commander: Colonel Gina Grosso
- Base phone number: (609) 754-1100
- Base area, in acres: 7400
- Electricity price: 9.82 cents/kWh
- Propane price: 152.2 cents/gallon
- Heating oil price: 222 cents/gallon
- Biomass availability, 25 mi radius (tons): 1408
- Biomass availability onsite: TBD
- Website: http://www.jointbasemdl.af.mil/index.asp
- Key features: Joint Base McGuire-Dix-Lakehurst is a tri-service military installation that combines McGuire Air Force Base, Naval Air Engineering Station Lakehurst, and Fort Dix. This joint military installation is the first of its kind in America. Navy Lakehurst occupies 7430 acres, U.S. government owned, in the 1 million acre Pinelands National Reserve in central New Jersey. The base is 45 miles east of Philadelphia, Pennsylvania, 50 miles south of New York City, 60 miles north of Atlantic City and 10 miles west of the Atlantic Ocean. It is in close proximity to Fort Dix to the west, forming a 42,000 acre complex to make-up Joint Base McGuire-Dix-Lakehurst. The combination of base size, long winter season, heating and electrical prices, and regional availability of woody biomass in close proximity to the base make this a strong candidate for this project.

21. Joint Base Pearl Harbor-Hickam

- Base Commander: Captain Richard Kitchens
- Base phone number: (808) 473-2888
- Base area, in acres: ~500
- Electricity price: 26.13 cents/kWh
- Propane price: N/A
- Heating oil price: N/A
- Biomass availability, 25 mi radius (tons): 1200
- Biomass availability onsite: TBD
- Website: http://www.cnic.navy.mil/PearlHarbor-Hickam/index.htm
- Key features: Joint Base Pearl Harbor-Hickam is a joint Army and Navy installation. Pearl Harbor is a lagoon harbor on the island of O‘ahu, Hawai‘i, west of Honolulu. Much of the harbor and surrounding lands is a United States Navy deep-water naval base. It is also the headquarters of the U.S. Pacific Fleet. The facility is in proximity to natural forestry resources, but the amount of biomass actually onsite remains TBD. The high electricity prices in the region are also an attractive fit for the CPC project.

3.2 Other Recommended Sites

3.2.1 Sites in Colorado that are close to CPC

1. Peterson Air Force Base
    - Base Commander: Colonel Stephen Whiting
    - Base phone number: (609) 754-1100
    - Base area, in acres: 1300
    - Electricity price: 6.4 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 1484
    - Biomass availability onsite: TBD
    - Website: http://www.peterson.af.mil/
    - Key features: The 21st Space Wing is headquartered at Peterson Air Force Base, Colo., and is the Air Force's only organization providing missile warning and space control to unified commanders and combat forces worldwide.

2. Schriever Air Force Base
    - Base Commander: Colonel Wayne R. Monteith
    - Base phone number: (719) 567-5306
    - Base area, in acres: 3800
    - Electricity price: 6.4 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A
    - Biomass availability, 25 mi radius (tons): 1484
    - Biomass availability onsite: TBD
    - Website: http://www.schriever.af.mil/
    - Key features: Schriever AFB is the home of the 50th Space Wing, the Space Innovation and Development Center, the Missile Defense Agency's Joint National Integration Center, 310th Space Group and numerous tenant organizations.

3. Fort Carson
    - Base Commander: Major General David G. Perkins
    - Base phone number: (719) 526-1269
    - Base area, in acres: 138000
    - Electricity price: 6.4 cents/kWh
    - Propane price: N/A
    - Heating oil price: N/A

- o Biomass availability, 25 mi radius (tons): 814
- o Biomass availability onsite: TBD
- o Website: http://www.carson.army.mil/
- o Key features: Fort Carson is the home of the 1st, 2nd, 3rd and 4th Brigade Combat Teams of the 4th Infantry Division, the 10th Special Forces Group, the 71st Ordnance Group (EOD), the 4th Engineer Battalion, the 759th Military Police Battalion, the 10th Combat Support Hospital, and the 43rd Sustainment Brigade.

3.2.2 Largest resource base within 25 mile radius ($70/ton)

Installation Name	Approximate Area, Acres	State	Electricity Price, cents per kWh	Total Forestry Residues @ $50/ton	Total Forestry Residues @ $70/ton
Cp McKean Naval Recreation Center	21	Washington	4.42	311410	317322
NS Bremerton	430	Washington	4.42	307575	313379
Naval Shipyard Puget Sound	310	Washington	4.42	306271	312047
Barksdale AFB	22000	Louisiana	5.94	306554	311678
Manchester Fuel Depot	280	Washington	4.42	300235	305852
Naval Undersea Warfare Center Keyport	300	Washington	4.42	297115	302670
Ft Polk	198000	Louisiana	5.94	282008	291922
Fleet and Industrial Supply Center Puget Sound	220	Washington	4.42	284597	289849
Ft Lewis	88000	Washington	4.42	282529	285040
McChord AFB	4500	Washington	4.42	267010	269376
NAS Meridian (Outlying Field Joe Williams)	1300	Mississippi	5.94	262406	265371
Pacific Bch	56	Washington	4.42	253356	255850
NAS Meridian	8000	Mississippi	5.89	242707	246044
NAS Whiting Field (Outlying Field Evergreen)	410	Alabama	7.69	240883	244079
Ft Gordon	55000	South Carolina	5.64	234561	239588
Ft Lee	5400	Virginia	6.87	216656	225416
NS Everett	220	Washington	4.42	214253	216201
Ft Stewart	280000	Georgia	6.25	210134	214263
Harvey Point Defense Testing Activity	2000	North Carolina	5.89	197335	213264
Ft Bragg (Camp Mackall)	8000	South Carolina	5.64	201691	208891
Columbus AFB	4400	Mississippi	5.89	195391	199889
Ft Benning	183000	Georgia	6.25	193290	197895
Ft A P Hill	75000	Virginia	6.87	188723	197057
Marine Corps Air Station Cherry Point (Outlying Field Oak Grove)	950	North Carolina	5.89	186303	194390

3.2.3 Largest installations with access to >100,000 tons/yr

Installation Name	Approximate Area, Acres	State	Electricity Price, cents per kWh	Total Forestry Residues @ $50/ton	Total Forestry Residues @ $70/ton
Ft Stewart	280000	Georgia	6.25	210134	214263
Ft Polk	198000	Louisiana	5.94	282008	291922
Ft Benning	183000	Georgia	6.25	193290	197895
Ft Bragg	153000	North Carolina	5.89	146336	147722
Marine Corps Base Camp Lejeune	143000	North Carolina	5.89	96886	103737
Ft Knox	109000	Kentucky	4.84	102094	102094
Ft Campbell	104000	Kentucky	4.84	110567	112249
Ft Lewis	88000	Washington	4.42	282529	285040
Ft A P Hill	75000	Virginia	6.87	188723	197057
Naval Surface Warfare Center Crane	62000	Indiana	5.58	135042	135042
Ft Rucker	61000	Alabama	5.61	115783	118175
Ft McCoy	60000	Wisconsin	6.43	111560	126038
Marine Corps Base Quantico	59000	Virginia	6.87	113067	117502
Ft Gordon	55000	South Carolina	5.64	234561	239588
Ft Jackson	52000	South Carolina	5.64	166930	170841
Arnold AFB	39000	Tennessee	5.92	117852	117852
Beale AFB	24000	California	9.47	116561	116561
Barksdale AFB	22000	Louisiana	5.94	306554	311678
Red River Army Depot	19000	Texas	6.57	188963	193595
Letterkenny Army Dep	18000	Pennsylvania	7.11	131976	131976
Naval Weapons Station Charleston	18000	South Carolina	5.64	106254	108720
Naval Submarine Base Kings Bay	17000	Florida	7.69	134136	139163
Anniston Army Dep	16000	Alabama	5.61	132008	138193
Blue Grass Army Dep	15000	Kentucky	4.84	105569	110020

4.0 Future Directions and Recommendations

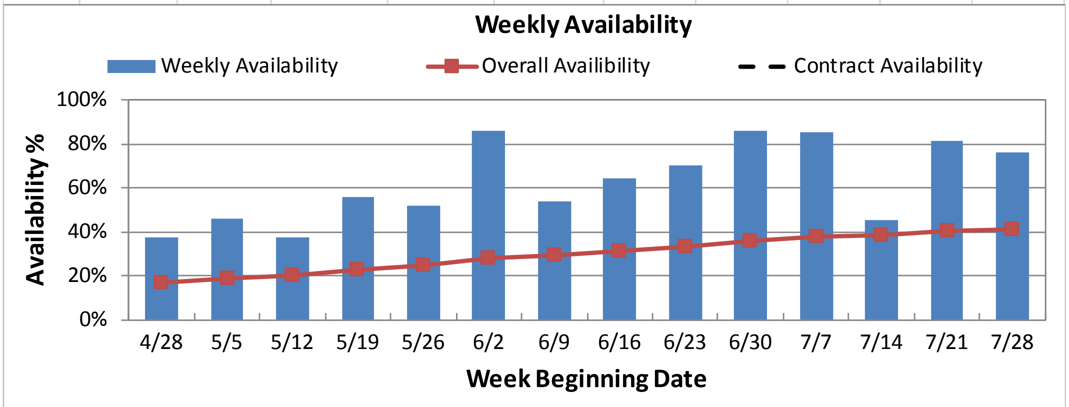
Our analysis indicates that there is a significant amount of woody biomass co-located with military installations throughout the United States. This presents a significant opportunity in terms of power generation through gasification and co-generation that would generate significant savings throughout the DoD complex and reduce the greenhouse gas footprint associated with more traditional means of generating electricity (e.g., coal firing). This intersection of facilities and feedstocks presents a significant opportunity for the potential deployment of hundreds, if not thousands, of the CPC units.

APPENDIX C. DELIVERED POWER DURING DEMONSTRATION

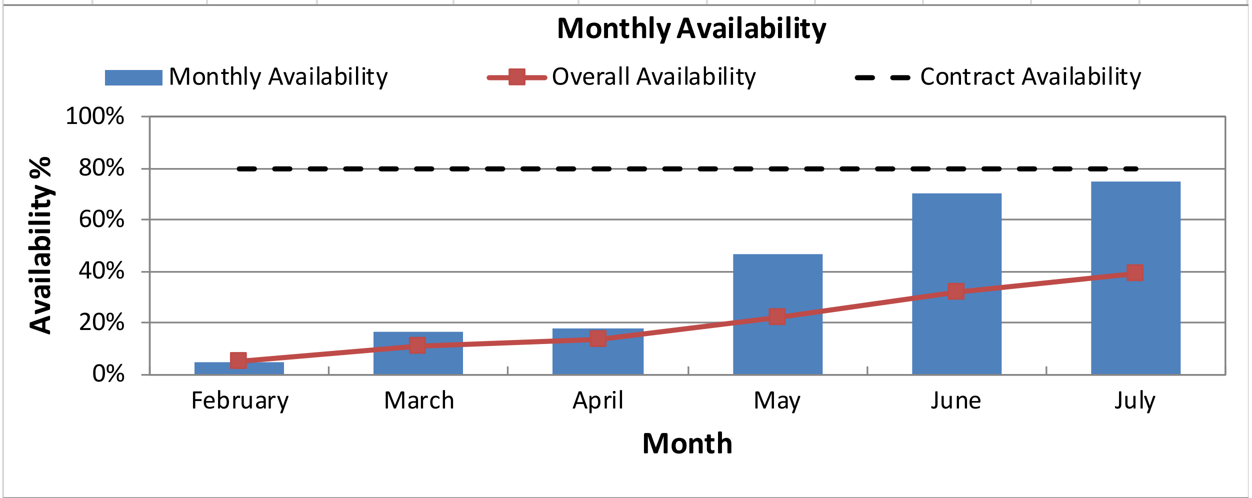
BioMax 100 Performance at Fort Carson with Softwood Chips

Weekly Basis

Week #	Week Beginning Date	Run Hours	Total Volume Producer Gas (Nm^3)	Net Energy Generated (kWh)	YTD Energy Generated (kWh)	Weekly Availability	Cumulative Run Hours	Total time	YTD Availability
1	2/10/2013	7.4	4888.0	-454.1	-454.1	4%	7.4	168	4%
2	2/17/2013	6.7	5417.9	-446.4	-900.5	4%	14.0	336	4%
3	2/24/2013	25.3	10721.7	1014.8	114.3	15%	39.3	504	8%
4	3/3/2013	22.9	9535.3	800.4	914.6	14%	62.3	672	9%
5	3/10/2013	22.9	10311.7	935.8	1850.5	14%	85.2	840	10%
6	3/17/2013	33.5	11660.8	1402.4	3252.9	20%	118.6	1008	12%
7	3/24/2013	36.1	10975.4	1524.8	4777.7	21%	154.7	1176	13%
8	3/31/2013	50.4	14881.6	1971.1	6748.7	30%	205.1	1344	15%
9	4/7/2013	49.7	16442.7	2539.9	9288.6	30%	254.8	1512	17%
10	4/14/2013	11.5	5616.9	-140.5	9148.1	7%	266.3	1680	16%
11	4/21/2013	6.6	4722.6	-7.1	9141.0	4%	272.9	1848	15%
12	4/28/2013	63.2	17673.1	2503.8	11644.8	38%	336.1	2016	17%
13	5/5/2013	77.5	22491.6	5185.3	16830.1	46%	413.6	2184	19%
14	5/12/2013	63.4	17779.0	3165.0	19995.1	38%	476.9	2352	20%
15	5/19/2013	93.3	25059.8	5986.3	25981.4	56%	570.2	2520	23%
16	5/26/2013	87.1	24581.4	5020.1	31001.5	52%	657.3	2688	24%
17	6/2/2013	144.2	33552.1	8408.5	39410.0	86%	801.5	2856	28%
18	6/9/2013	90.6	19504.8	4813.2	44223.2	54%	892.1	3024	30%
19	6/16/2013	108.4	21807.7	6885.6	51108.8	65%	1000.6	3192	31%
20	6/23/2013	118.3	22531.1	6557.8	57666.5	70%	1118.9	3360	33%
21	6/30/2013	144.6	27102.1	8532.2	66198.7	86%	1263.4	3528	36%
22	7/7/2013	143.1	26539.3	7547.1	73745.8	85%	1406.5	3696	38%
23	7/14/2013	76.4	14956.7	3342.9	77088.7	45%	1482.9	3864	38%
24	7/21/2013	136.5	23605.6	5726.0	82814.7	81%	1619.5	4032	40%
25	7/28/2013	73.0	14527.1	2700.5	85515.3	76%	1692.5	4128	41%



Period Ending Day	Month	Run Hours	Total Volume Producer Gas (Nm^3)	Net Energy Generated (kWh)	YTD Energy Generated (kWh)	Monthly Availability	Cumulative Run Hours	Total time	YTD Availability	contract
28	February	33.3	18601.7	-240.0	-240.0	5%	33.2575	672	5%	80%
31	March	121.4	45851.1	4966.8	4726.8	16%	154.6839	1416	11%	80%
30	April	130.0	46715.3	4742.7	9469.5	18%	284.6386	2136	13%	80%
31	May	348.6	96592.7	19744.1	29213.6	47%	633.2653	2880	22%	80%
30	June	505.1	107642.6	29876.6	59090.2	70%	1138.3	3600	32%	80%
31	July	554.1	100966.1	26411.1	85501.4	74%	1692.5	4344	39%	80%



APPENDIX D. NON-HAZARDOUS NATURE OF CPC's BIOCHAR

STATE OF COLORADO

Bill Owens, Governor
Douglas H. Benevento, Executive Director

Dedicated to protecting and improving the health and environment of the people of Colorado

4300 Cherry Creek Dr. S.
Denver, Colorado 80246-1530
Phone (303) 692-2000
TDD Line (303) 691-7700
Located in Glendale, Colorado

Laboratory Services Division
8100 Lowry Blvd.
Denver, Colorado 80230-6928
(303) 692-3090

http://www.cdphe.state.co.us

Colorado Department of Public Health and Environment

September 1, 2004

Mr. Robb Walt, President
Community Power Corporation
8420 S. Continental Divide Road
Littleton, CO 80127

Dear Mr. Walt:

The Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division (the Division) received your letter dated August 19, 2004 which describes the "char and ash" waste stream generated as a by-product of the biomass downdraft gasification process. In light of the information that you provided, it does not appear that the char waste produced by a BioMax unit would meet the definition of a hazardous waste. This determination is based on the fact that the waste stream neither exhibits a hazardous waste characteristic, nor is it a listed hazardous waste.

For clarification, the Division would like to point out that, for the purpose of making a hazardous waste determination, the Pensky-Martens closed-cup ignitability test is only required when you have a liquid waste stream. Your letter indicates that the char waste is solid in form, and is not capable under standard temperature and pressure of causing fire through friction, absorption of moisture, or spontaneous chemical changes. Therefore the Division agrees that this waste stream does not exhibit the ignitability characteristic.

Similarly, in accordance with 6 CCR 1007-3 Part 261.22, by definition only an aqueous or liquid waste stream can exhibit the characteristic of corrosivity.

Should you have any questions concerning this letter, feel free to contact our Customer Technical Assistance Line at (303) 692-3320 or toll free (888) 569-1831, extension 3320.

Sincerely,

Frederick R. Dowsett
Compliance Coordinator
Hazardous Materials and
Waste Management Division

FRD/CMS/cms

Community Power Corporation

Energy Systems for Sustainable Power

August 19, 2004

Fred Dowsett
Compliance Coordinator
Hazardous Materials and Waste Management Division
Colorado Department of Public Health & Environment
4300 Cherry Creek Drive South
Denver, CO 80246

Dear Mr. Dowsett:

Community Power Corporation (CPC) is a research and development company located in Littleton that develops and tests modular biopower systems and other renewable energy-related products and services. One of CPC's principle products is a small modular biopower system called the BioMax. The BioMax system uses a proprietary downdraft gasification technology to convert woody residues such as wood chips and wood pellets to a very clean producer gas consisting of approximately 20% hydrogen, 20% carbon monoxide, 3% methane with the balance being water vapor, carbon dioxide and nitrogen. This fuel–gas is used to operate standard internal combustion engine/generators, solid oxide fuel cells, and other prime movers. CPC has developed this technology in cooperation with and funding from the US Department of Energy, the US National Renewable Energy Laboratory, the US Forest Service's Forest Products Laboratory and the California Energy Commission. A key objective of the five-year technology program was the development of environmentally friendly technology suitable for the 21st century.

During operation of the BioMax unit, char particles and ash are produced as by-products of the biomass downdraft gasification process. The char and fine ash particles are collected in a dry, non-condensing, filter system while the unit is running and are removed by vacuum for disposal after shutdown.

We are in the process of evaluating the options for disposal of the approximately 2% of the raw woody feedstock that result in a combination of char and ash fines. For instance, a BioMax 15, generating 15kW of electricity will produce about 0.79 pounds of char and ash per hour, or around 6.3 pounds per 8-hour day of operation.

The purpose of this letter is to request a ruling from you as to whether or not the char and ash waste produced by a BioMax unit should be classified as hazardous waste.

CPC has evaluated the properties of the waste produced by the BioMax units from the perspective of the four characteristics listed in the Colorado Hazardous Waste Regulations (6 CCR 1007-3 Part 261 Subpart C). The properties of the char waste are described below under the headings of ignitability, corrosivity, reactivity, and toxicity.

8420 S. Continental Divide Road
Littleton, Colorado 80127 USA
www.gocpc.com
Telephone: (303) 933-3135
Fax: (303) 933-1497

Ignitability

On July 22, 2004, CPC collected a representative sample of char waste from a BioMax 15 endurance test run conducted the previous day. The char sample was immediately placed in a glass jar with a Teflon seal (provided by Evergreen Analytical Laboratory) and refrigerated to preserve any volatiles. Later that day, the sample was transported in a pre-cooled ice chest to Evergreen Analytical Laboratory's testing facilities in Wheat Ridge.

Evergreen Laboratory performed a Pensky-Martens closed-cup ignitability test (method SW 1010) on the sample and found that its flashpoint at 620 mm Hg was above 140 °F. The char was not "ignitable" by this test.

Although the char waste is combustible when dry, it would not be capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture, or spontaneous chemical changes.

Corrosivity

The char waste that is produced by the BioMax units is neither aqueous nor a liquid. When water is added to the char, an alkaline mixture is created with a pH of approximately 12 to 13, as tested by pHydrion Instant Check paper, made by Micro Essential Laboratory. This alkalinity is due to the presence of calcium and potassium oxides in the char and ash.

Reactivity

The char waste that CPC produces does not exhibit the characteristic of self-ignition nor does it react with water. Over the past five years we have not experienced auto-ignition of this char if it is cooled to ambient temperature prior to exposure to air. The char waste is not an explosive material.

Toxicity

During the gasification process, the char collected in the filters and char drums of the BioMax units can adsorb between 2% - 10% tars by weight. The tars appear to be adsorbed on the large surface area of the char. The adsorbed tars have been analyzed by the National Renewable Energy Laboratory and are known to be polycyclic aromatic hydrocarbons containing small amounts of benzene, naphthalene, dimethyl naphthalene, acenaphthalene, fluorene, anthracene, phenanthrene, pyrene, dimethyl pyrene, benzo(a)anthracene, chrysene, fluoranthene, benzo(b)fluoranthene, benzo(k)fluoroanthene, and benzo(a)pyrene. The tars are a by-product of the gasification process and were never used as chemical solvents.

CPC also asked Evergreen Analytical Laboratory to evaluate a sample of the same char waste as was used for the ignitability test for characteristics of leachable toxicity. Using Test Method 1311 (method SW 8260B) the leachate sample from this char was analyzed for the presence of the Toxic Characteristic Leaching Procedure (TCLP) volatiles of benzene, 1,1 dichloroethene, 1,2 dichloroethene, 1,4 dichlorobenzne, 2-butanone, carbon tetrachloride, chlorobenzene, chloroform, tetrachloroethene, trichoroethene, and vinyl chloride. None of these compounds were found in the leachate at levels at or above the regulatory limits cited in Table 1 under Section 261.24 of the Colorado Hazardous Waste Regulations. The char sample was non-toxic by this test.

Other Waste Characteristics

The char and ash waste produced by the BioMax units contains fine particles and is powdery when dry. Adding water to the waste to make it damp can eliminate its dusty characteristics, if necessary.

I have enclosed copies of Evergreen Laboratories' analytical test results. If you need any more information, please contact our chief chemical engineer, Jim Diebold, at CPC by phone at 303-933-3135 x236 or by email at jdiebold@gocpc.com.

Thank you for any guidance you can provide about the proper classification of CPC's char waste.

Sincerely,

Robb Walt

Robb Walt, President
Community Power Corporation

Enc. (Evergreen Analytical Laboratory test results)

Cc: Joyce Williams
Hazardous Waste Compliance/Enforcement Unit Leader
Colorado Department of Public Health & Environment
4300 Cherry Creek Drive South
Denver, CO 80246

ENDNOTES. REFERENCES

[1] http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html#c=homeEnergy&p=reduceOnTheRoad&m=calc_currentEmissions

[2] http://www.epa.gov/climatechange/ghgemissions/gases/ch4.html

[3] Report # DOE/EIA-0573(2001), *Emissions of Greenhouse Gases in the United States.*

[4] Jefferson, A. "The Effect of Biochar on Heavy Metal Sorption: Nickel, Copper, Lead, and Cadmium," downloaded from http//kearney.ucdavis.edu/undergrad_fellowship_reports/JeffersonPowerPoint.pdf

[5] Community Power Corporation web site at www.gocpc.com

[6] Schifsky, C. (2002) "Tech: Gas Vs. Diesel, Which is Best for You?," Truck Trend, Oct. 1. (downloaded 11/26/2013 from http://trucktrend.com/features/tech/163_0210_diesel_vs._gas/viewall.html)

[7] Anon. (downloaded 11/26/2013) "Cummins 5.9 and 6.7 liter six-cylinder engines", http:///www.allpar.com/mo par/cummins-diesel.html

[8] Unused

[9] Paap, S.; West. T.; and Simmons, B. (2010) "Final Report. CPC Demonstration Project Site Selection and Evaluation," Sandia National Laboratories.

[10] Dowsett, F.R., Compliance Director, Hazardous Materials and Waste Management Division, Colorado Department of Public Health, Letter to Robb Walt, Community Power Corporation, 9/1/2004

[11] www.colorado.gov/airquality/permits/guide.pdf dated 8/20/10, downloaded 9/23/10

[12] http://www.cdphe.state.co.us/ap/Titlev.html#whoneeds downloaded 9/23/10

[13] http://agr.wa.gov/PestFert/Fertilizers

[14] Diebold, J.P. Appendix C. "Benzene Mitigation Efforts" in "Fielding of Deployable Waste to Energy (WTE) system for Forward Operating Bases and Installation Training Areas. Final Demonstration and Validation Test Report," ASA(IE&E)-ESOH, Contract No. W74V8H-04-D-0005, (Task No. 0462-A2), to Concurrent Technologies Corporation, 100 CTC Drive, Johnstown, PA 15904.

[15] http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html down loaded 11/26/2013

[16] http://epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_SummaryTables.pdf
downloaded 11/26/2013

[17] http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html#c=homeEnergy&p=reduceOnTheRoad&m=calc_currentEmissions

[18] http://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPLLPA_PRS_dpgal_w.htm

[19] L_3 Communications quotation of June 27, 2008 received by CPC on July 7, 2008.

[20] www.globalsecurity.org/military/systems/ground/mep-tqg.htm (downloaded 11/6/2013)